TEXT PROBLEM WITHIN THE BOOK ONLY

General Biology

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General Biology

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PREFACE TO SECOND EDITION

We appreciate the kind reception accorded the first edition of this book. From teachers and students using it have come valuable suggestions which have proved most helpful in preparing this revision. We have attempted to incorporate all suggestions that contribute to a clearer and better presentation, but we realize that no textbook will meet, in all details, the requirements of all teachers.

The general plan of organization of the first edition has been retained with certain modifications. The last chapter of the first edition, rewritten and enlarged, is the first chapter of the new edition. The discussion of hormones constitutes a new chapter entitled "Chemical Coordination." The results of recent investigations of both hormones and vitamins have necessitated a rewriting of these portions of the text. The discussions of bacteria, genetics, evolution, and conservation have also been extended. Throughout the text many minor changes have been made to correct previous errors and to clarify statements of facts. Complying with the request of many teachers, the authors have compiled a glossary, which they trust may not tempt the students to develop habits of stereotyped thinking.

The illustrations of the first edition have been re-examined. Many of the figures have been redrawn, and new illustrations have been added. In making these changes we have adhered to our original policy, viz., that each illustration must have definite pedagogical value.

Today, changes are taking place so rapidly that there is need for greater stress on principles. With this in mind additional emphasis has been placed on scientific method. Throughout the text we have attempted to illustrate the method of scientific investigation by presenting in detail certain experimental procedures which have led to important biological discoveries. On every hand we are confronted with high-powered advertising involving much distortion of truth. We have given certain examples of such advertising and have attempted to show how scientific analysis at once reveals the true nature of such false claims. It is our hope that this emphasis may encourage the student to develop a more scientific attitude in his

analysis of propaganda of all kinds and thus become less gullible and more intelligently independent.

To inspire interest in biological investigation we have continued our original plan of presenting occasional glimpses of the history of biology through brief biographical sketches and other historical data.

Recent studies indicate the need of more emphasis on the fundamental principles underlying hygiene and of teaching more facts concerning health. At various points in the text, we have attempted to stress health problems as far as space permitted.

It is still our aim to develop a textbook in biology for students at the college level. Moreover, we believe that we cannot teach principles until the student possesses an adequate background of facts, for facts are implements of thought. We have attempted to present sufficient factual material to enable the student to obtain an accurate and working comprehension of biological principles as well as to develop an appreciation of the living world of which he is a part.

This second edition is not merely a selective revision. It is in large measure a rewritten book. It is our hope that students and teachers alike will find it much improved and more helpful in the study of biology.

In the preparation of this edition we wish to acknowledge again the assistance of all those mentioned in the preface to the first edition. We are also deeply indebted to the teachers and students who have kindly submitted suggestions. We are especially indebted to Dr. A. M. Showalter of Madison College, Harrisonburg, Va., who in compliance with our request has offered helpful criticism. We also wish to acknowledge the assistance of Mr. Maynard Garner and Miss Rose Eleanor Garner in the preparation of a large number of the new illustrations. Proper credit is given in the legends for all photographs or illustrations obtained from various other sources.

P. D. S.
B. R. W.

CONTENTS

CHAPTER I

WHAT IS BIOLOGY?

Each day we are accustomed to see various kinds of living things —grass, trees, flowers, flies, birds, cats, dogs, people, and many others. Indeed, we are so accustomed to seeing these living forms that we seldom pause to question the nature of their existence. What do they do and why? What makes them alive? What is life? If we should wish to know more about these living things we must study biology. **Biology** (*bios*—life; *logos*—study) is the science of life or the study of all living things, both plants and animals. It seeks to understand and explain those complex and fascinating processes which collectively constitute this peculiar phenomenon called life. This life is manifested in ourselves and in every living plant and animal. A living entity, regardless of structure, size, or behavior, is called an **organism,** and these organisms exist in a bewildering variety of forms that inhabit the earth's soil, its waters, and its atmosphere.

WHY STUDY BIOLOGY?

Like the dog and the cat, the bird and the bee, we, too, are animals, and since we are all players in this great drama of life we should be specially interested in the roles we are playing. The study of biology will give us information concerning our entrance, our varied performances, and our exits. We shall learn something about the structure of our bodies, the workings of the different parts, and the conditions that may either hinder or help the working. Such information should enable us to take better care of ourselves and to live more efficiently. The person who has the best understanding of his physical machinery should know best how to use it. Moreover, man is a social creature with a tendency to live in groups, as is indicated by his towns and cities. Living in communities has created many additional health problems such as epidemics, health quarantines, sewage disposal, and pure water supply. The solution of these problems involves a knowledge of biology.

In studying biology we not only acquire a better understanding of ourselves but we also obtain information concerning other living creatures—the other animals and the plants. This is very important because, unlike primitive man, we do not depend upon hunting and fishing but we cultivate plants and rear animals to supply our needs. Biology informs us about the requirements of crop plants and domestic animals, their diseases and methods of controlling them, the way to obtain better varieties and larger yields, and it also provides other knowledge necessary for successful plant and animal husbandry. From grassland and forest we derive food supplies, industrial and construction materials, game and fur-bearing animals. The proper utilization and necessary conservation of these natural resources demand a knowledge of the fundamental principles of biology, such as are being applied in the conservation measures introduced within recent years.

A knowledge of biology also makes possible a fuller appreciation of life and all living organisms. We do not enjoy a beautifully colored sunset because of its value in dollars and cents but rather because of the emotion it stirs within us. So it is with the living forms about us, the cheering music of birds, the chatter of a squirrel, the beauty and fragrance of the rose—all such phenomena are the motivating agents of emotions that enrich and quicken our personal experiences. The more we know about the living organisms in our environment the greater will be our understanding of their habits and our enjoyment of them, not because they furnish food or help to increase our income, but because they are our interesting neighbors.

Finally, biology gives us a better understanding of all human relationships. As an animal, man's entire development, including his intellect, is a biological development, and with this fact in mind we can better understand his reactions and his relations with his fellow men. His customs, his many organizations, his family interests, his curiosity, travel, and sports—indeed all his reactions are matters of biological interest. A knowledge of biology is essential for the understanding of both psychology and sociology. Inherent in man's nature is his curiosity, the drive to seek for the new, the *why* and the *how*. Insatiable curiosity is the natural mainspring for the continued acquisition of knowledge. Where did man come from? Where and how did life originate on the earth? What is the cause of disease? Curiosity arouses such questioning, and such questions in turn reveal something of the complex relationship in which man lives. We may never arrive at the final answers, but our understanding will increase in proportion to the increase in our knowledge of biology.

THE FIELD OF BIOLOGY

We have said that biology is the science of life or the study of all living things. Too often this great life science has been so subdivided and groups of animals and plants have been so divorced from one another that the broad, general principles true of all living things become very obscure. Thus plant biology (botany) and animal biology (zoology) may readily come to be considered two separate and distinct realms rather than subordinate states of the empire of biology.

For our introduction to biology we shall deal with the subject as a unit, including all living forms, both plant and animal. For more intensive and critical studies it is necessary to subdivide this unit into a number of highly specialized parts each of which is concerned with some particular phase of plant and animal life. These subdivisions of biology are now generally recognized as follows:

- Morphology—The study of the form and structures of animals and plants.
  - Anatomy—The study of gross structures.
  - Histology—The study of tissues.
  - Cytology—The study of cells.
- Taxonomy—The grouping and naming of organisms.
- Physiology—The study of the working or functioning of organisms.
- Ecology—The study of the environmental relations of organisms.
- Heredity or genetics—The study of the inheritance of organisms.
- Embryology—The study of the development of organisms.
- Animal behavior and animal psychology—The study of adjustments and reactions of the organism as a whole.
- Paleontology—The study of the fossils of pre-existing plants and animals.
- Philosophical biology—The study of the origin of life and living forms (evolution).

These fields are so integrated and so interrelated that the sum of these parts makes the total of the "pure" science of biology. Other recognized divisions which have grown out of "pure biology" may be considered collectively as "applied biology." Progress in applied biology naturally depends upon the advancements made as a result of investigations concerned with the fundamental principles of biology or "pure biology." A list of the fields of applied biology may be arranged as follows:

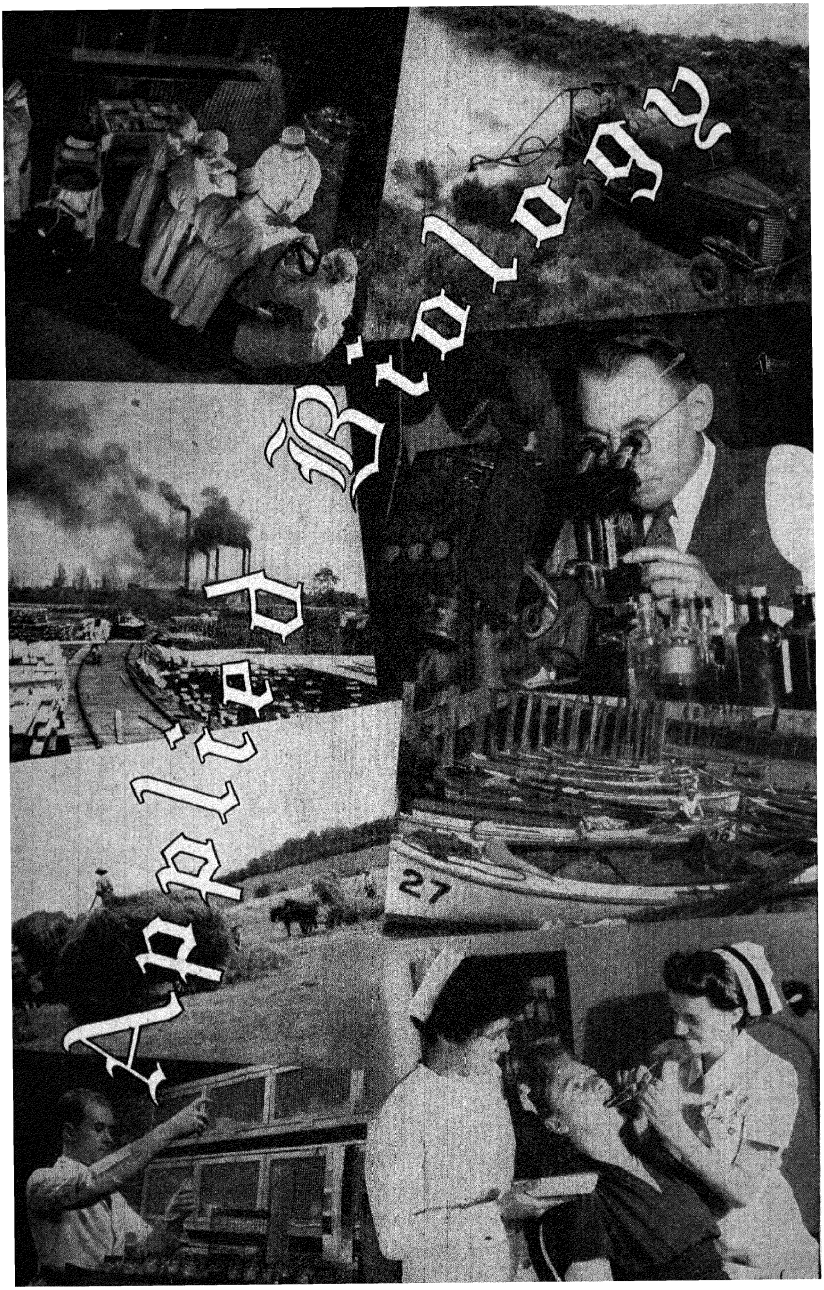


FIG. 1. Applied biology. Photographs furnished as follows: *upper left,* The Abbot Laboratories; *bottom left,* Parke, Davis and Company; *bottom right,* David Huntsberger; "fishing boats" by Fish and Wild Life Service, U. S. Department of the Interior; all others by the U. S. Department of Agriculture.

Agriculture.
- Horticulture—Culture of trees, shrubs, and vegetables.
- Agronomy—Culture of such field crops as grains and other grasses, cotton, and legumes.
- Silviculture or forestry.
- Animal husbandry or the care of animals.
- Applied entomology—The study of insects and their control.
- Fur farming and fish culture.

Homoculture or the culture of man as an individual.
- Medicine.
- Dentistry.
- Nursing.
- Sanitation and public health.

Sociology—Human group relationships.
- Eugenics and euthenics—Human betterment through inheritance and improvement of the environment.
- National policies—Immigration.

Psychology—Human behavior.

This very brief outline indicating the scope of biological study should serve to stimulate interest in the subject and also to broaden our perspective and give us a keener appreciation of the many phases of this life science.

BIOLOGY AND OTHER SCIENCES

In the development of the program of formal education, biology has only comparatively recently joined the aristocracy of the sciences comprising mathematics, astronomy, physics, geology, and chemistry. In many respects, the science of biology has been developed by aid of the contributions of the other sciences, and any advancement made in the future must depend upon contributions from these same sources. A complete understanding of biological science necessarily involves a knowledge of all the kindred sciences.

Astronomy. The earth, a planet and member of the solar system, is the home of living things. This fact naturally invites speculation and theorizing about the origin of the earth and its place in the heavens. The influence of the sun and the changing seasons on the life of animals and plants gives to biology a definite interest in the solar system. We shall also see that the moon has an apparent influence on various physiological rhythms. Thus we see that astronomy makes its contribution to biology.

Chemistry. No adequate concept of the living organism and the organic world can be formed without some understanding of the inorganic realm. Any attempt to study physiology or the functioning of a plant or animal, ignoring completely such items as matter, elements, atoms, compounds, synthesis, and decomposition, would be utterly absurd. A knowledge of the nature of the basic substance of life itself, protoplasm, and also of the structure and function of the organism, rests on the foundations of chemistry.

Physics. A knowledge of certain physical processes helps us to understand how food is absorbed and distributed, and how wastes are eliminated. The source of energy for both animals and plants is explained in the analysis of the sunbeam. The modern theory of nervous conduction involves a knowledge of electricity. No one could possibly attempt to study the eye and vision without having some knowledge of optics and light. It was a physicist, Helmholtz, who explained the basis of hearing and the functioning of the human ear.

Geology. Adequate comprehension of animal and plant distribution, a phase of animal and plant ecology, is possible only by the aid of geology. One of the greatest contributions made to philosophical biology—in fact to the entire field of philosophy—namely, the theory of evolution, is rooted in, and grew from evidence revealed by, the rock strata of the earth. On the other hand, it is by the aid of biology in the form of animal and plant remains entombed in the rocks that the geologist studies the widely separated areas of land and shows the extent not only of one deluge and water-covered land but of many of them. He makes assertions quite astonishing to the layman that a present mountain top was once sea bottom and that an old rock quarry, sometime in the past, may have been a treacherous quicksand along a river bank where strange huge beasts came to slake their thirst.

Mathematics. The average biologist may give mathematics little credit for the development of his science. Indeed, it is often stated that biology is one science that makes use of little if any mathematics. Nevertheless, it is quite clear that mathematics has played a very significant part in the past, and there can be no doubt that its role in the future development of biology will become increasingly important. The modern theory of heredity was born when Mendel subjected his breeding experiments to mathematical analysis. Not only the student of heredity, but also the physiologist, believes that the hope of the future of biology as a science rests in the making of quantitative studies of various life phenomena which can be ex-

pressed in mathematical formulas and equations. It seems hardly necessary to call attention to the fact that any experiment involving measurements must employ mathematics.

Few if any biological processes do not involve principles and laws developed in one or more of the other sciences. For example, a most important process, photosynthesis, in which the elements of water and carbon dioxide combine (chemistry) to form sugars and starches, is found to be dependent upon sunlight (astronomy). This process involves the phenomena of osmosis and diffusion of liquids and gases for the intake and transportation of raw materials and manufacture of food, and an analysis of the sunbeam as the source of energy (physics). The decomposition of raw materials and their synthesis into manufactured materials, as well as the nature of the manufactured food, are of the essence of chemistry. Finally, mathematics furnishes the tools whereby the amount of raw materials taken in can be balanced against the quantity of manufactured products and the resultant byproducts. Thus, in dealing with one biological process, mathematics and three other sciences are definitely involved. If the answer to the riddle of life is ever ascertained, the discovery will be made by biologists who are thoroughly trained not only in biology but also in the fields of chemistry and physics.

THE SCIENTIFIC METHOD

Through the years, the efforts of the scientists have produced a tremendous body of knowledge. The psychologists and neurologists have learned much about the workings of the mind and the influence of emotions. They tell us "how to make friends and how to influence people." The numerous discoveries of the scientists have been put to good use in improving living conditions, in increasing the food supply, in alleviating suffering, in the better control of disease, in the general betterment of mankind, thus making the world a better place in which to live. All the achievements of the scientists have been accomplished by certain procedures that collectively constitute what is called the **scientific method,** and the continued application of this method of working results in the development of the scientific attitude.

The quest for knowledge or truth by means of the scientific method consists essentially of three steps: **observation, analysis,** and **conclusion.** Very often the scientist also makes use of **experimentation.** In the early beginnings of the scientific method, its application usually stopped short of experimentation, which, of course, also involves

observation. For example, observation may suggest that light is necessary for plant life. This suggestion may then be adopted as a tentative explanation or **hypothesis.** Interest may cease at this point, or it may promote experimentation to test the truth or falsity of the hypothesis. Various plants may be tested to ascertain their reactions to different degrees of light ranging from total darkness to intense light. The records of the observations made may be accumulated in notes called **data.** Numerous experiments may be tried yielding more data, and, after careful analysis and evaluation of all these data, conclusions are drawn. If all the results of numerous experiments support the same conclusion, the hypothesis will seem to be confirmed. This apparently correct hypothesis may be subjected to further experimentation and observation, and if the results of this additional testing continue to square with the hypothesis it then becomes a **theory.** Finally, when this theory emerges from subsequent testing, substantiated by all the facts available, it becomes a law. The facts supporting theories are widely disseminated so that they are made known to all who may be interested in them. Others may repeat the experiments, and, should additional facts be uncovered that show the theory to be false, it will have to be modified or even abandoned altogether. The scientist insists on having factual evidence to support each conclusion, either tentative or final. He must accept the truth arrived at by his method of working even though it is the direct opposite of what he would like to believe. In other words, he must have an open mind. He must be intellectually honest. If all the data concerning a certain process lead to a conclusion contrary to all those previously accepted, he must have the courage to announce his findings and conclusions, although doing so may mean ridicule and even abuse. Thus we see how the scientific mind works and what is meant by the scientific attitude, that is, this certain way of looking at things, and insisting on accurate observation and unmistakable, tangible evidence for the solution of any given problem.

We have attempted to say that the scientific method is the utilization of a certain procedure to discover truth; that all statements must be supported by objective evidence (data) obtained through observation alone or accompanied by experimentation, rather than by argument, appeal to authority, and armchair speculation. Not only must data be accumulated; they must also be analyzed and evaluated by an unprejudiced mind.

Sifting the true from the false. Never before in his history has man been subjected to so many devices designed to influence his

thinking and his behavior. Scientific discovery and invention have greatly improved our means of communication by giving us more books, a greater number of magazines and newspapers replete with advertisements, the radio, flashing neon signs, the sound film, and the amplifier. Apparently television is just around the corner. Today, man is being subjected to continual assault by various individuals and organizations trying to "sell him something." Unfortunately, there are in almost every community men who are willing to take advantage of and use other men and discoveries for their own pleasure and selfish ends. Extravagant claims are made for motor oils, face powders, tooth pastes, hand lotions, and patent medicines. The advertisements of many of these drugstore concoctions claim such marvelous remedial properties that one can readily expect them to cure all ills from colds to cancer. We are urged to stock the pantry with special brands of bread, breakfast foods, and other eatables, specially treated and enriched with certain essential vitamins. Men can be made more handsome and women more attractive by consuming patent hormone tablets. Man is bombarded by the radio, magazines, and newspapers, with all types of social and political nostrums. With all this advertising propaganda impinging on them our senses are apt to become fatigued, and we cease to think clearly and to evaluate critically.

The problem confronting us then is to acquire a technique to sift the wheat from the chaff; the true from the false. It would seem that a scientific attitude and the application of the scientific method would go a long way toward solving the problem of arriving at the truth. One example must suffice. Of special interest to everyone is the program set up by the American Medical Association in its effort to "debunk" various so-called cures. The medicine or preparation is subjected to scientific laboratory testing and analysis by competent chemists and physicians. The manufacturer is then compelled to print the truth concerning his product, as revealed by the experimental tests. Figure 2 shows very strikingly what the scientific method and insistence on the promulgation of truthful advertising can accomplish. It also demonstrates how the application of scientific analysis can protect the average man if he will only read carefully and think critically.

The hope of man and democracy, in fact of civilization, rests upon man's ability to analyze propaganda, to detect sham, and to discriminate between truth and falsehood. Just as science has contributed much to our comfort and physical welfare, so has it supplied us with a technique of straight thinking.

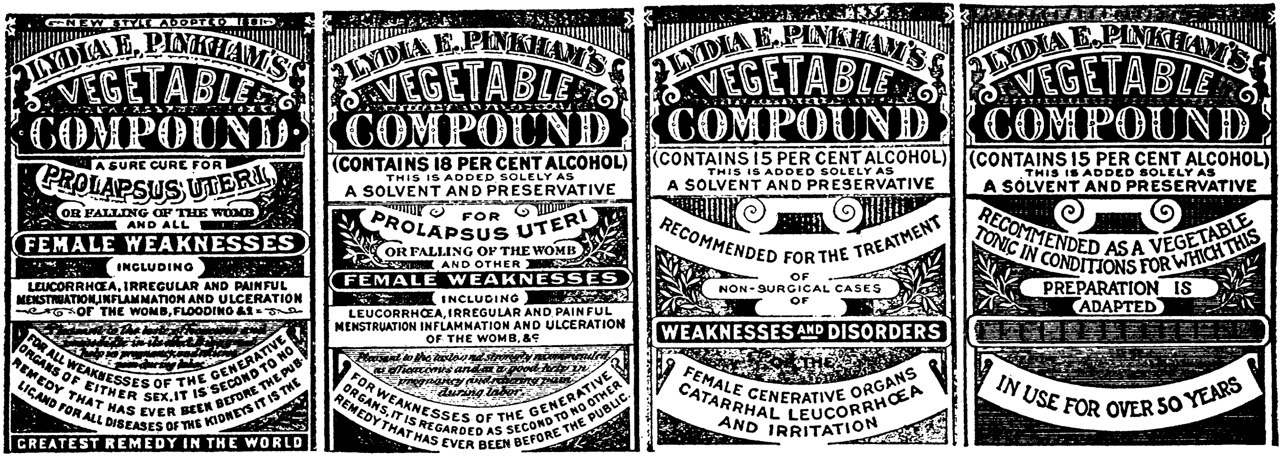


Fig. 2. An illustration of the application of the method of science. Contrast the early claims made in the label at the left to the ones made in the label at the right after the remedy and its claims had been subjected to scientific analysis by the government. The present label (*right*) means nothing. *By permission of American Medical Association.*

CHAPTER II

LIFE: WHAT IS ITS NATURE? WHAT ARE THE CHARACTERISTICS OF LIVING THINGS?

As we begin the study of life or biology we are faced with the task of distinguishing between non-living things like the rocks, minerals, and water, and living animals and plants, often called **organisms.** In biology we study these living organisms and attempt to discover what peculiar fundamental structural and functional features mark them off from the non-living or lifeless bodies.

PROTOPLASM

The important feature common to all living organisms is that they are made up of a basic building material called **protoplasm** (*protos*—first; *plasma*—form or mold). This peculiar substance was first named in 1840 by Purkinje, who observed it in animals. In 1846, Von Mohl applied the same term to the living substance in plants. Only as we come to know something of the peculiar characteristics and activities of protoplasm as manifested in living plants and animals are we able to catch some glimpses of what life is and what constitutes a living organism.

Protoplasm exists as such only in living organisms, of which it forms the essential material, whether the organism is a microscopic bacterium, a man, a tree, or a whale. Whatever the organisms may be, protoplasm is readily recognized by certain unique attributes or properties, yet it may differ somewhat in the different species of animals or plants. Through the microscope the protoplasm of any particular cell or of different cells may vary in its appearance. When examined ultramicroscopically, protoplasm is found to be full of small suspended particles giving it a homogeneous appearance. When the particles are large enough to be seen by the microscope, protoplasm has a granular appearance; that is, it is made up of rather large liquid particles suspended within a liquid. When specially prepared for microscopic study, protoplasm is killed and coagulated. In its coagulated state it seems to be made up of a network or reticulum, but we must remember that this is now "dead protoplasm."

Physically, protoplasm is a clear, grayish, somewhat transparent liquid with varying degrees of viscosity or ability to flow. The viscosity varies from time to time from a **sol** state where protoplasm is almost as fluid as water to that of a somewhat sticky or jellylike **gel** state. But even in this jellylike state droplets of liquid are present. This characteristic of fluidity of varying degrees as well as certain other peculiarities of structure indicates that protoplasm is a **colloidal** (*kolla*—glue) system. Colloidal systems are characterized structurally by the presence of innumerable ultramicroscopic particles dispersed or scattered through a continuous medium.

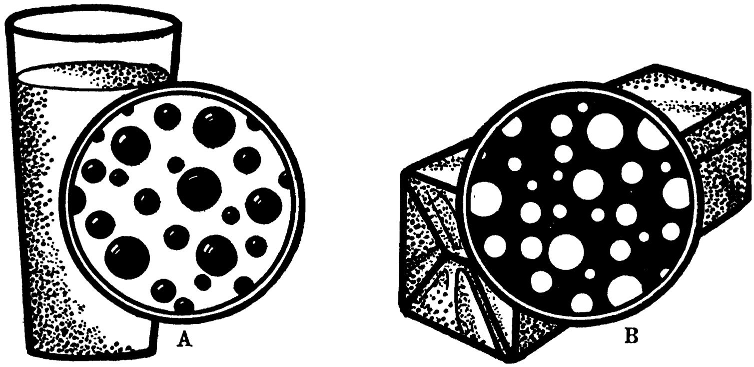


FIG. 3. Illustration showing the difference between the sol state (cream), *A*, in which water is the continuous phase containing dispersed droplets of oil, and the gel state (butter), *B*, in which oil is the continuous medium containing dispersed water droplets.

In a colloidal system the substance in which the particles are scattered is called the **dispersion medium** or **continuous phase,** and the scattered particles, whether solids or liquid droplets, form the **dispersed** or **discontinuous phase.** For example, in a cloud in the sky, the air is the continuous phase and the droplets of water (moisture) are the dispersed phase. In cream, water is the continuous phase and droplets of fat the dispersed phase. The phases are reversed in butter, where oil is the continuous phase and water the dispersed phase (Fig. 3). There is also a marked difference in the fluidity of cream and butter.

In protoplasm the continuous medium is a watery solution. In addition to the ultramicroscopic particles of the dispersed phase, protoplasm usually contains visible structures such as crystals, droplets of oil and fats, and bits of various other materials. Collectively these materials are mostly either wastes or stored food.

The solid particles and droplets of the different fluids found in protoplasm vary greatly in size. Some substances, like inorganic

salts, sugars, and amino acids, in a liquid break up into very small particles which will pass through a filter or a membrane. Such substances are called **crystalloids,** and they form true solutions. Proteins, starches, and fats in a solvent break up into much larger particles, forming what are known as colloidal systems. If solid particles

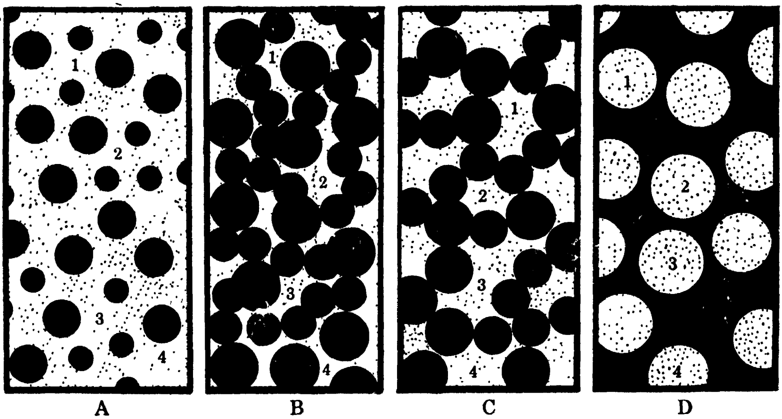


FIG. 4. Stages in the formation of a gel. *A,* A fluid sol consisting of droplets (black) scattered through a dilute solution (stippled). *B,* the droplets (black) take up water (stippled), enlarge, and come into contact. *C,* the coalescence of droplets (black) forms a spongelike structure or gel. *D,* the droplets (black) here form a continuous medium enclosing globules (stippled) of the original (*A*) dispersion medium. *Adapted from Deming "General Chemistry." By permission of the author and of the publisher, John Wiley & Sons.*

are dispersed in a liquid a **suspension** is formed, for example, starch in water. If liquid particles are suspended or dispensed through a liquid an **emulsion** is produced. For example, when oil is shaken up in water an emulsion is formed of small oil droplets dispersed and suspended in the water. Milk is a good example of an emulsion. Many of the substances found in protoplasm are components of either suspensions or emulsions.

Thus we see that physically protoplasm is a rather heterogeneous mixture of solids within liquids, liquids within liquids, and liquids within solids. Some of these liquids or droplets are in themselves mixtures or colloidal suspensions. Surrounding these liquid regions, or **phases,** and solid regions (also phases) there are so-called **surface films,** adsorbed on which may be other substances.

The structure of protoplasm varies in different cells and different organisms. It likewise varies with the parts of the cell, according

to the conditions in and around the cell. Sometimes the entire cell seems to be liquid **(sol)**; at other times it is somewhat gelatinlike **(gel).** As the living cell ages the protoplasm shifts from a liquid or sol to a semisolid or gel stage (Figs. 3 and 4).

Matter and energy. For a long time material or matter making up protoplasm, in fact all material involved in the life processes of living organisms, was called **organic matter** as distinct from the so-called lifeless material or **inorganic matter.** But chemical analysis of living matter which, unfortunately, is killed in the process of analysis, reveals the presence only of certain substances found also in inorganic matter. Further, a study of the chemistry of protoplasm reveals that, essentially, nothing different in the nature of the energy processes is involved. It seems necessary, then, if we are to understand the fundamental processes of the living organism, to consider certain elementary concepts of matter and energy.

We live in a world of substance **(matter)** and forces **(energy).** Matter is defined as anything that occupies space and has mass and weight. Matter, organic or inorganic, is made up of submicroscopic particles called **molecules.**

Molecules are the smallest particles into which any particular kind of matter can be divided without losing its identity. These molecules are in turn made up of smaller particles called **atoms,** usually two or more of which are always present in definite proportion or fixed numbers for each kind of molecule. Thus a molecule of water has two atoms of a substance called hydrogen and one atom of another substance called oxygen (Fig. 5).

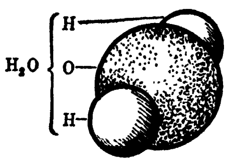


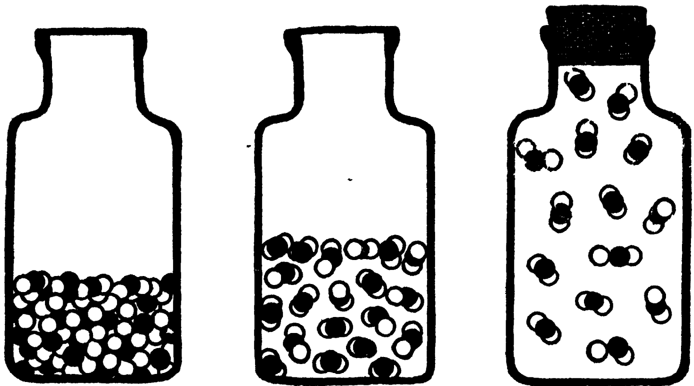
FIG. 5. Model of a molecule of water.

Substances made up entirely of one kind of atoms are called **elements,** the simplest substances of which matter is composed. An element retains its identity, however finely divided. Over ninety different elements are known to science, but only thirty-four of them are usually found in animals and plants. The elements most commonly found in protoplasm, together with their symbols, are as follows:

ELEMENT	SYMBOL	ELEMENT	SYMBOL
Oxygen	O	Potassium	K
Carbon	C	Iron	Fe
Hydrogen	H	Magnesium	Mg
Nitrogen	N	Calcium	Ca
Phosphorus	P	Sodium	Na
Sulphur	S	Chlorine	Cl

One atom of oxygen would be designated O; two atoms as O_2 or 2O. If two or more atoms of two or more elements unite in definite proportion, a molecule of a substance called a **chemical compound** is formed; e.g., CO_2 (carbon dioxide); H_2O (water). In protoplasm the elements just listed usually occur as chemical compounds.

It is possible to prepare from either elements or compounds, or from both, material that is not a compound but a **mixture.** Ordinary concrete is a good example of a mixture, for it is easy to identify



A B C

Fig. 6. Diagram illustrating relative position and arrangement of molecules of a substance in the three different states: (*A*) solid, (*B*) liquid, and (*C*) gas.

the stone, sand, and cement of which it is composed. These materials retain for the most part their original characteristics or properties and may be present in varying proportions. But in water (H_2O), hydrogen and oxygen both lose their own peculiar properties and unite in definite proportion to form a chemical compound that has very different properties (Fig. 5).

Matter may exist in three forms or states—**solids, liquids,** and **gases.** The states or forms of any particular kind of matter depend upon the freedom and range of motion of the component molecules (Fig. 6). These molecules are traveling in paths restricted by the number of other molecules present in a given space and by their attraction for one another. Thus the molecules of any substance in the gaseous state have longer paths, more space in which to move, and less attraction for one another than molecules of the same matter in the liquid state. Water, for example, may exist as a solid (ice), a liquid, or as steam (gas). To change water into steam requires heat, a form of energy. When water, as steam, changes from the

gaseous to the liquid state, heat is given off, or, in other words, energy is released. Heat, light, electricity, and movement are all forms of energy.

Every change in the form, composition, and motion of a body of matter involves a transfer or transformation of energy. Thus the power released by heat from coal to make gaseous steam from water to drive a steam locomotive is energy. The power released by the exploding gasoline that drives the automobile is energy. During recent years scientists have learned how, by splitting the atom, to release atomic energy, and the magnitude of this force or energy has been demonstrated in the almost incredible destruction wrought by the atomic bomb.

Energy, then, is the capacity for doing work. Energy capable of doing work, such as that stored in coal or gasoline, is called **potential energy.** Energy which is manifesting itself, that is, which is at work, is **kinetic energy.** We shall see that the organism, in order to live, must continually convert potential energy to kinetic energy.

In both the organic and the inorganic bodies chemical compounds are being formed constantly by the union of atoms of different elements, a process known as **synthesis** or building up. At the same time other chemical compounds are being broken down by a process of **decomposition.** The chemist indicates such syntheses and decompositions by a form of shorthand called **equations.** For example:

Synthesis: $$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \text{Energy} \rightarrow \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Decomposition: $$\underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} \rightarrow \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \text{Energy}$$

Thus all chemical changes involve some form of energy (heat, light, electric discharge). In synthesis, energy is absorbed. Later this energy may be released by decomposition of the compound.

Protoplasm has been chemically analyzed many times. Some have been inclined to regard it as a "single complex chemical compound," but the modern view is that protoplasm is a complex organization of chemical compounds: proteins, carbohydrates, fats, water, salts, and other materials. Thus it follows that the peculiar properties of protoplasm are determined by the organization of the chemical substances that enter into its composition.

Carbohydrates (*carbo*—coal; *hydor*—water). It is probable that all living protoplasm contains some carbohydrates, familiar examples of which are sugars and starches. They are made up of the

elements carbon, hydrogen, and oxygen—the hydrogen and oxygen usually in the same proportion as in water (H_2O) (Fig. 7). Carbohydrates most often found in living organisms may be generally classified as:

Monosaccharides (*monos*—single; *saccharon*—sugar)	Ex. $C_6H_{12}O_6$	Examples are grape sugar (glucose); sugar in honey (fructose).
Disaccharides (*di*—two)	Ex. $C_{12}H_{22}O_{11}$	Examples are cane sugar (sucrose); milk sugar (lactose).
Polysaccharides (*poly*—many)	Ex. $(C_6H_{10}O_5)_n$	These sugars are made up of some multiple of $C_6H_{10}O_5$, which in starch is around 20 or $(C_6H_{10}O_5)_{20}$. Examples are starches of various kinds, glycogen, and cellulose.

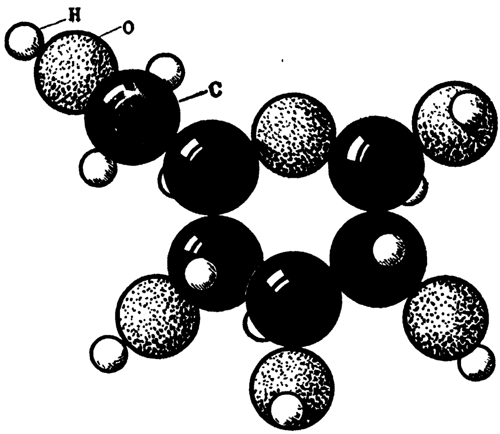


FIG. 7. Model of a molecule of a simple carbohydrate, glucose ($C_6H_{12}O_6$). *Redrawn from Amberson and Smith, "Outline of Physiology." By permission of the artist, Norris Jones, and the Williams and Wilkins Company.*

The monosaccharides and the disaccharides are very soluble in water, but the polysaccharides are relatively insoluble. Disaccharides can readily be changed to monosaccharides by the addition of a molecule of water, a process called **hydrolysis** (*hydor*—water; *lysis*—loosening). Molecules of monosaccharides can be built into (synthesized) disaccharides by the elimination of a molecule of water. Similarly, polysaccharides may be synthesized or hydrolyzed.

Carbohydrates are used mostly as fuel or energy reserves in the organism. The cell walls forming the skeletal framework of plants are composed mainly of carbohydrates. Carbohydrates are stored in plants in the form of various sugars but mostly as the more

stable starches and cellulose. In animals they are stored as animal starch or glycogen.

Fats and other lipids. Like the carbohydrates, these compounds contain carbon, hydrogen, and oxygen; but the oxygen is present in much smaller quantities, and the hydrogen and oxygen are not present in the same proportion as in water, as will be seen from the formula of a typical fat, $C_{51}H_{104}O_9$. The **true fats** or simple lipids are familiar to us as butter, lard, tallow, and olive oil (Fig. 8).

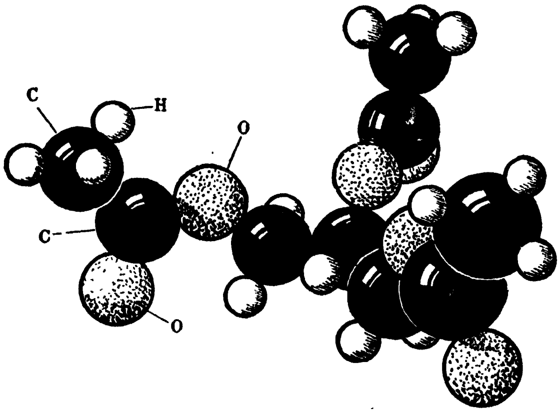


FIG. 8. Model of a molecule of the simplest fat, triacetin ($C_9H_{14}O_6$). *Redrawn from Amberson and Smith, "Outline of Physiology." By permission of the artist, Norris Jones, and the Williams and Wilkins Company.*

When fats are decomposed by hydrolysis they are found to be made up of **glycerol,** commonly called glycerine, and **fatty acids.** In fact, each molecule of a fat is a combination of one molecule of glycerol and three molecules of the same or different fatty acids.

Just as fats can be decomposed into glycerol and fatty acids, so they can be synthesized from these two kinds of molecules. In plants and animals the close relation between carbohydrates and fats seems to indicate the origin of fats from carbohydrates. For example, in ripening seeds the amount of carbohydrates decreases and fat increases, whereas the reverse is true when the seed germinates. Fats are energy producers, and they are used by animals and plants as a convenient form in which to store reserve energy.

The **compound lipids** are closely related to the true fats. Like the fats, they are insoluble in water. In addition to C, H, and O, some of these compounds called **phospholipids** may contain N and P. A good example of a phospholipid is a substance called **lecithin,** found

in practically all living cells. In the eggs of all species of animals it is the major foodstuff used by the developing embryo.

A physiologically important group of lipids is the sterol group. There are a considerable number of sterols, and originally it was thought that they were synthesized by plants alone. It is now known that certain animals, at least, can synthesize cholesterol, the only sterol that can be readily absorbed from the intestinal tract. This sterol is present in large amounts in the brain and nerve tissues of higher animals. It is also the most common constituent of human gallstones. Ergosterol when irradiated with ultraviolet light has the same properties as vitamin D.

Proteins. Proteins are extremely complex chemical compounds whose molecules may contain thousands of atoms. Some rather common and well-known examples of proteins are **albumin** (egg white), **myosin** (lean meat), and **glutenin** (in flour). Proteins are composed chiefly of the elements carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Sulphur (S) usually is present, and often phosphorus (P). Sometimes other elements may occur. The large complex protein molecules are combinations of simpler organic compounds called **amino acids.**

Proteins are essential in the structure and life of protoplasm. The biochemist, when he attempts an explanation of life, usually thinks in terms of proteins. Their large molecules and complex chemical make-up enable proteins to react with a large number of other substances. This makes for a complex system of chemical interactions, that is, a series of syntheses, decompositions, resyntheses, and further decompositions—in other words, a constant complex series of changes that involve release, transformation, and storage of energy. Proteins have a variety of functions in the living protoplasm. Some, for example hemoglobin, aid in respiration; others furnish energy; still others may form protective structures, such as outer skin, nails, and horns.

Water. Quantitatively, water is the most abundant constituent of protoplasm, in which it exists not only in the "free state" but also in combination with many chemical compounds, such as carbohydrates. In the free state, water may be present in protoplasm in proportions ranging from 40 to 96 per cent by weight. For example, water constitutes over 65 per cent of adult man and 96 per cent of some jellyfish. The gray matter of the brain of man is 80 per cent water. In some water plants water may constitute 98 per cent by weight.

Water owes its extreme biological importance to the essential role it plays in many life activities. It is important in the manufacture of carbohydrates by the green plant. It dissolves a greater number

of substances than any other liquid and thus in large measure assists chemical reactions among the dissolved substances in the protoplasm. It makes protoplasmic movement possible. In general, the more water present, the greater the protoplasmic. activity. Tissues of young and more active organisms contain more water than those of older organisms. Water regulates the temperature of the organism and assists in the digestion (hydrolysis) of many compounds. Moreover, the atoms of hydrogen and oxygen, of which water is composed, play a real part in the synthesis and decomposition of the various chemical compounds found in the cell.

Salts. A salt familiar to all of us is ordinary "table salt" or sodium chloride (NaCl). Some of the more common salts found in

Type of Salt	Example	Formula
Chlorides adding Cl	Sodium chloride	$NaCl$
Sulphates	Sodium sulphate	Na_2SO_4
adding SO_4	Potassium sulphate	K_2SO_4
Nitrates	Sodium nitrate	$NaNO_3$
adding NO_3	Potassium nitrate	KNO_3
Phosphates adding PO_4	Sodium phosphate	Na_2HPO_4
Carbonates adding CO_3	Calcium carbonate	$CaCO_3$

protoplasm are shown in the table. Other salts could be added to this list. Nitrates and nitrites are found chiefly in plants, chlorides in most animals, and calcium carbonate in both animals and plants.

Salts furnish raw material for food synthesis. Most salts are readily soluble in water. They enter into the formation of protoplasm and play important roles in the life processes of cells. Many supporting structures in organisms are made up chiefly of inorganic salts, for example, the phosphates and calcium carbonate found in bone, and silica, which often occurs in certain grasses.

Definite Organization

By necessity the very earliest biologists were interested in those structures of animals and plants that they could see with the unaided eye. About 1600, the use of glass lenses for magnification was discovered. Many scientists became interested in constructing magnifying instruments, particularly spectacles. Later, crude microscopes were built, and many observations were made of the more minute details of plant and animal anatomy. Robert Hooke (1665), using

his penknife, made some thin sections of cork which he examined with his microscope (Fig. 9); he found the cork to be made up of "little boxes or cells distinguished from one another" (Fig. 10). Hooke's observations were confirmed by others, and through the years there accumulated a mass of observations made microscopically on different plants and animals. As is the method of science, these observations, or data, were critically studied and about 1840

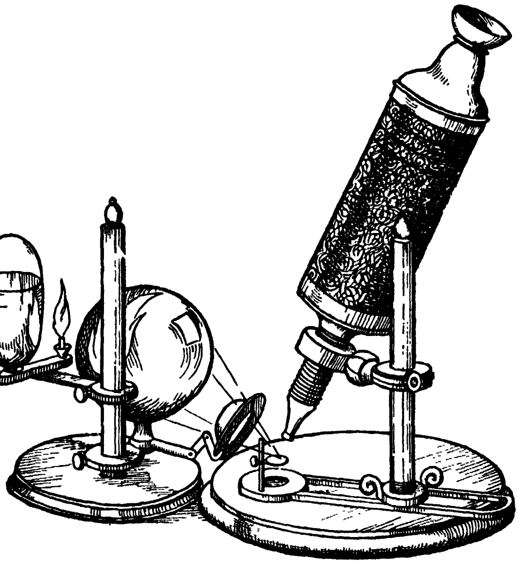


FIG. 9. Hooke's compound microscope. (*After Gustave Fassin, Scientific Monthly.*) *Redrawn from Greaves' "Elementary Bacteriology," by permission of the publisher, W. B. Saunders Co.*

led to the formulation of a far-reaching generalization or conclusion known as the **cell theory** or **cell doctrine.** The cell theory holds that **all living animals and plants are either single cells or complexes of cells and cell products, and the life of the organism as a whole is the combined life of its individual cells.**

As shown in Fig. 11, cells vary greatly in shape, depending upon their position and function in the organism. They may be cube-like, columnar, spherical, branched—in fact, the number of shapes is too great to be listed here. Just as the biologist's concept of cell form has changed since the time of Hooke, so has interest shifted from the shape of the container to the substance contained, that is, to the protoplasm itself. The contained protoplasm is now designated the **protoplast** (*protos*—first; *plastos*—something formed), and these **proto-**

plasts make up the structural units of the organism. Thus the term "cell" is now used to designate the protoplast with its confining membrane instead of an empty chamber enclosed by the wall.

Cells vary not only in shape but also in size. Some cells are so small as to be almost invisible through the microscope. The largest

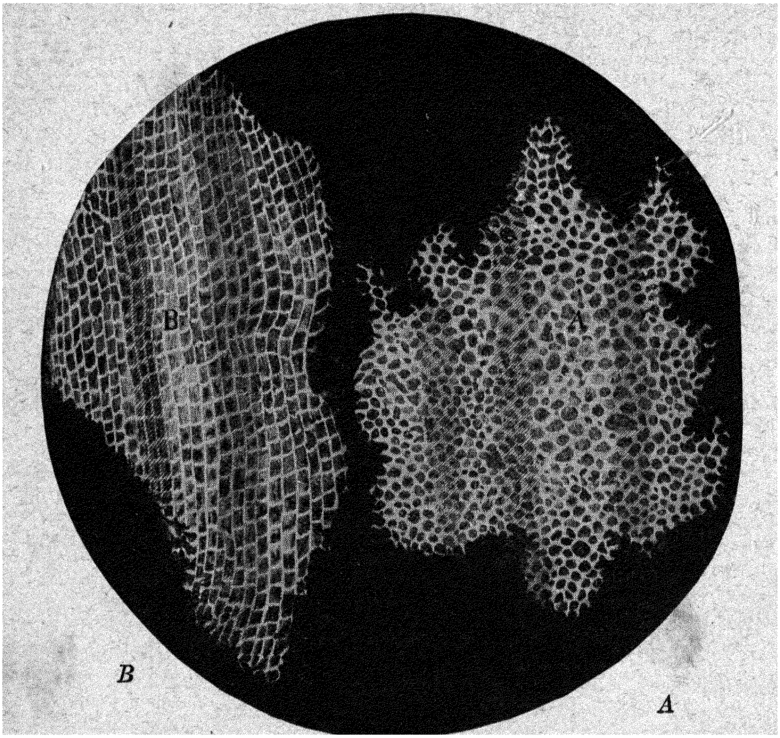


FIG. 10. Cork cells, cross (*A*) and longitudinal section (*B*), as Robert Hooke saw them under his microscope. *Reduced facsimile reproduction from his "Micrographia," published in 1665.*

living cell known at the present time is the ostrich egg, whose yolk is really the cell proper. Nerve cells, such as those in the lumbar region of the spinal cord, which are invisible to the naked eye, may have processes extending from the small of the back to the toes and may thus attain a length of several feet. However, most cells are microscopic.

For a number of years certain experimental evidence indicated that there were living units called viruses and bacteriophages, whose presence was known only by their reactions. Today, by the aid of the electron microscope, Fig. 12, these formerly invisible units have

been made visible, furnishing additional evidence in support of the earlier conclusions. There is a difference of opinion among bio-

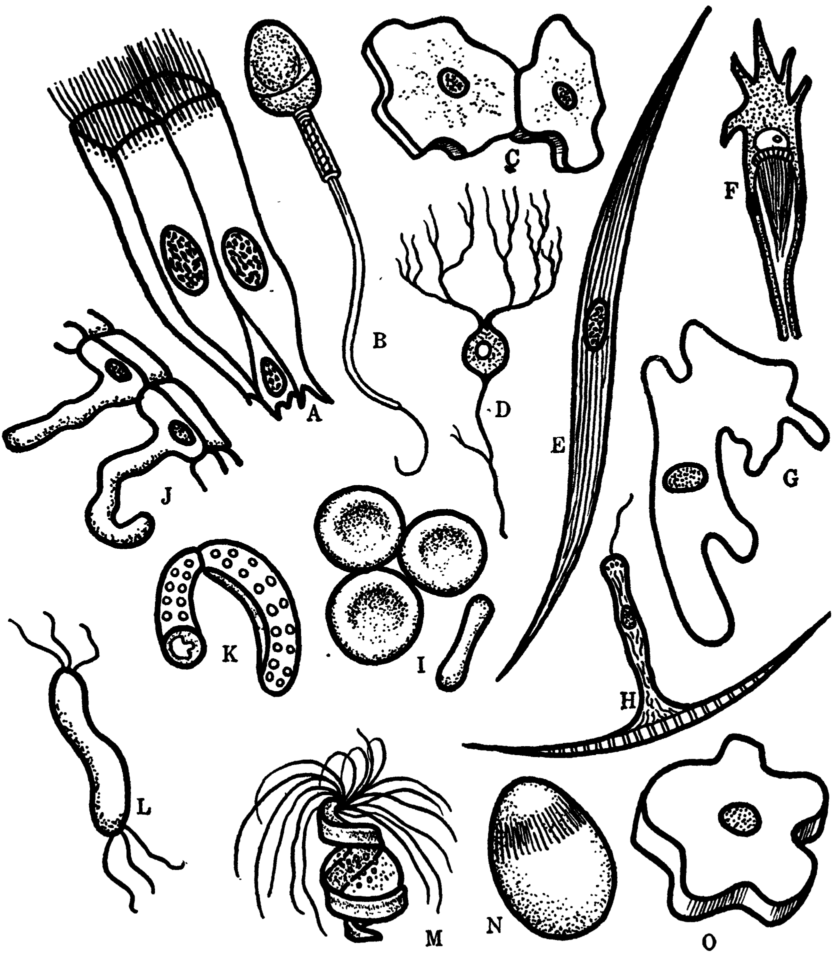


FIG. 11. Types of animal (*A–I*) and plant (*J–O*) cells: *A*, ciliated epithelial cell; *B*, spermatozoon; *C*, squamous epithelial cell; *D*, nerve cell; *E*, smooth muscle cell; *F*, flame cell; *G*, ameba; *H*, epithelio-muscular cell; *I*, red blood cells (corpuscles); *J*, epidermal cells of a root; *K*, guard cells of a leaf; *L*, bacterium; *M*, fern sperm; *N*, zoospore; *O*, epidermal cell of a leaf.

chemists as to whether the unit particles of viruses and bacteriophages are elementary living units or merely enormous protein molecules with certain properties peculiar to living cells. Some viruses are smaller than protein molecules, and others are larger than certain bac-

teria. Stanley points out that at least some viruses are complex proteins possessing the power of reproduction and showing evidence of heredity. They may be destroyed by the same agents that destroy living cells. Viruses cause certain specific diseases in animals, such as

FIG. 12. The electron microscope. *Photograph furnished by the Radio Corporation of America.*

measles, common cold, whooping-cough, and influenza; in plants they cause tobacco mosaic, blue stem of potatoes, cucumber mosaic, and curly top of cabbage, beets, and other vegetables.

The cell is not only a structural unit comparable to the separate bricks in a brick building, but it is also a functional or working unit. Thus, what an animal or plant *is* or *does* is what "its cells *are* or *do*." All life activities are cell activities, and it is only as we gain more

knowledge of biology that the full significance of the cell theory is realized.

Just as the living plant or animal is an organization of these cellular units, so is the individual cell organized and its protoplasm differentiated. The cell, irrespective of its shape, is usually made up of two well-defined parts, a **nucleus** (*nucleus*—nut or kernel) and the surrounding **cytoplasm** (*cytos*—hollow; *plasma*—something formed)

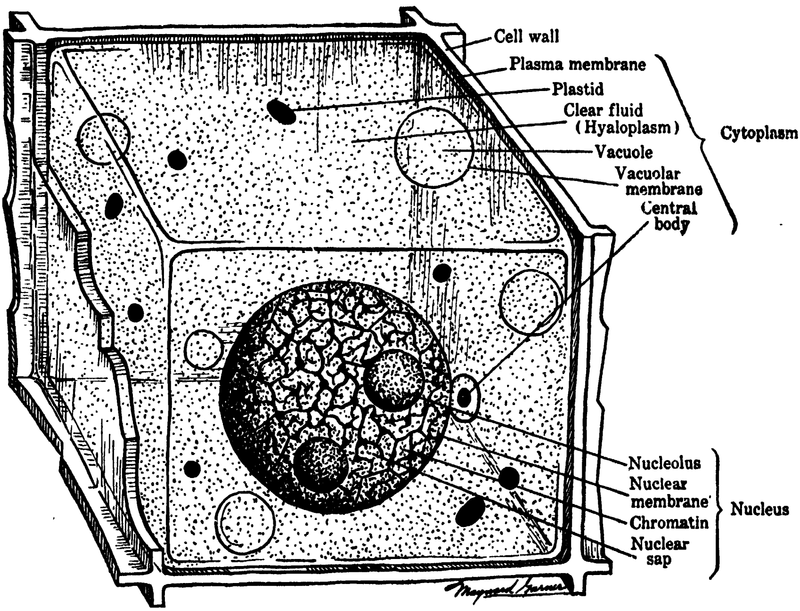


FIG. 13. Schematic drawing of a cell.

(Fig. 13). Enclosing the cytoplasm is the **plasma membrane** which controls to a large extent the movement of materials into and out of the cell. The plasma membrane may, in turn, be surrounded by and in close contact with the cell wall. Cell walls of plants are very prominent, but in animals they may be missing or at best hard to demonstrate. This cell wall is secreted or formed by the protoplast and is made up of more or less resistant substances. One of the most common components of the cell walls of plants is the complex carbohydrate **cellulose,** whereas many animal cells are surrounded by a membrane of complex protein material. Since this cell wall of plants consists of lifeless material, and the protoplast of living substance, we see that living organisms may be composed of both living and non-living material. Teeth, hair, finger nails, skin, and bones

contain much lifeless material. There is no living matter in a hair except at its root, and very little in bone. In a tree all the heartwood is dead, and the living cells are found outside this region.

The great bulk of most cells is made up of the cytoplasm. Included in the cytoplasm may be stored food in the form of starch, fat droplets, yolk granules, and other material. In many cells, especially those of plants, there are various bodies called **plastids.** Thus the green plant has many cells which contain green plastids called **chloroplasts** (*chloros*—green; *plastos*), used in food manufacture. Fluid-filled cavities known as **vacuoles** are often present; they play an important part in the metabolic or energy processes of the cells. Each vacuole is bounded by a protoplasmic membrane which influences the movement of materials into and out of the vacuole.

Near the nucleus, in the cells of some plants and of most animals, there is usually present a somewhat denser area of cytoplasm known as the **central body.** The central body, when present, is active in cell division.

Other cytoplasmic bodies that may be present are **chondriosomes** or **mitochondria** in the form of granules, rods, or filaments of various size. Near the nucleus there may be an irregular threadlike network called **Golgi bodies** or **dictyosomes.** The function of these structures is not known.

The nucleus is usually a somewhat spherical body having a variable position in the cell (Fig. 13). It is surrounded by a definite **nuclear membrane** of firmer consistency than the surrounding cytoplasm. Enclosed by the nuclear membrane is the **nucleoplasm,** which makes up the ground substance of the nucleus. The most noticeable material in the nucleus is the **chromatin** (*chromos*—color), which becomes clearly visible when stained with various dyes. Recent studies seem to indicate that the chromatin granules are thicker regions of delicate threads called **chromonemata** (*chromos; nemos*—thread). This chromatin is vitally concerned in heredity. Often one or more definite bodies of unknown function called **nucleoli** are present.

The nucleus governs and regulates the activities of the cell. The nucleus and the cytoplasm are mutually dependent. Cytoplasm cannot long exist without the nucleus, and the cell dies if the cytoplasm is paralyzed even though the nucleus is unimpaired. Apparently mutual interchange of materials must take place between these two parts of the cell if the cell is to carry on its normal functions.

Just as we have seen that protoplasm is organized into units called cells, so we find that groups of similar cells which perform some

particular function are organized into **tissues.** These tissues in turn may be grouped and organized to form an **organ,** such as the heart of an animal or the leaf of a plant. Organs may be grouped and closely interrelated because of some special function to form a **system,** such as the digestive system of man with such organs as the stomach, liver, and pancreas. Finally, in most of the multicellular (many-celled) plants and animals these systems together with certain other tissue combinations may constitute an organism, a living entity such as a plant or an animal. In unicellular (one-celled) plants and animals, we find no tissues or organs such as have just been described. However, there are differentiations and specializations of the constituent protoplasm by which certain essential life functions are carried out.

Organismal Theory. Within more recent years some biologists have maintained that the cell is not the fundamental unit of structure and function but rather the unit is the organism as a whole. According to this interpretation the organism is more than a mere aggregation of individual cells. Each plant and animal is regarded as a more or less continuous mass of protoplasm within which cells are formed as centers of differentiation. The scientists who advance this view regard it as a more logical basis for the explanation of development, differentiation, and correlation. In all such activities the coordination among the cells and tissues is brought about by the organism functioning as a unit, just as, in the game of football, the team is the unit rather than any one of the individual players. Because of this emphasis on the organism as a whole, the theory has been called the **organismal theory.** When first proposed the idea encountered general skepticism, but more recently it has been more and more favorably received by an increasing number of biologists. Perhaps we may ultimately discover that the cell theory and the organismal theory merely emphasize two different aspects of living organisms. We may think of the cell theory as an interpretation of the plan of structure and the organismal theory as an explanation of the correlation and coordination of the individual cells. The two views incorporated in one biological theory may help us to understand more fully the nature of the organism.

Metabolism

It is common knowledge that one must eat in order to live. Living, as we think of it, involves a constant outgo of energy in the form of heat and mechanical movement. This flow of energy is maintained by the intake and assimilation of food. If we think but a moment we realize that food is imperative not only for man but for all living animals and plants, since all are composed of that basic substance, protoplasm. Now when we extend this idea of energy release to all organisms we find that, in addition to the energy expended as heat

and motion, energy may be released in the form of light (fireflies, fox-fire) and electricity (certain fishes, such as the electric ray).

In this release of energy living protoplasm is consuming its own material, particularly the carbohydrates and fats, by burning them or, scientifically speaking, by **oxidation.** The burning of coal and wood is an oxidative process, but oxidation in organisms goes on at a much lower temperature. Oxidation in the living organism is known as **respiration** (*re*—again; *spirare*—to breathe). It usually involves the intake of free oxygen into the cell where cell contents are oxidized to release energy, with the consequent formation of carbon dioxide (CO_2) and water (H_2O) as waste products. As will be pointed out later, some types of organisms may live in the absence of oxygen; in fact, free oxygen is toxic for certain forms of bacteria. However, respiration is constantly taking place in all organisms. Its cessation means death, and thus it is one constant invariable characteristic of living matter. Oxidation of carbohydrates and fats may be summarized by the following equations:

Carbohydrate: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$

Fat: $C_{57}H_{104}O_6 + 80O_2 \rightarrow 57CO_2 + 52H_2O + \text{Energy}$

This oxidation of carbohydrates and fats, which we have just called respiration, is not the only decomposition process going on in the cell. Proteins likewise are broken down but not to the same degree as the other two substances just mentioned. All protoplasm may be broken down into simpler substances much less rich in energy, which are finally given off or eliminated from the organism, as carbon dioxide, water, urea, and various salts. This complete breaking-down process is called **catabolism;** in it we see the organic material of the cell broken down and changed back to inorganic material.

As pointed out above, the organism is constantly receiving fresh supplies of material, which it distributes to its cells where it is worked over and synthesized into new proteins, fats, and carbohydrates. In fact, new protoplasm is being built to replace that lost in catabolism. This building-up phase of metabolism is known as **anabolism.**

If the organism is to continue to live, that is, if life is to remain in the protoplasm, both processes must go on, anabolism building protoplasm and furnishing potential energy, and catabolism transforming the potential energy to kinetic. If anabolism exceeds catabolism, as so often happens in young animals and plants, material

accumulates in the cell and growth takes place. In old age catabolism exceeds anabolism, and eventually and inevitably death ensues. In this life process (metabolism) we see the inorganic material being synthesized into organic and new material constantly replacing the old, which is thrown back to the inorganic world. But through all these material and energy changes the organism retains its peculiar individuality, whether it be a camel or a stalk of corn. This is life. The various aspects of metabolism will be discussed in more detail in subsequent chapters.

Another characteristic of living protoplasm is its ability to grow. As has been pointed out, when anabolism exceeds catabolism, i.e., when synthesis exceeds decomposition, material accumulates within the cell, and additional living protoplasm is built up from inorganic or non-living material. In marked contrast is the method of growth of such inorganic things as crystals, snowballs, or icicles, where new material is added to the outside.

Now there are limits to the size that an individual cell can attain. If anabolism continues to exceed catabolism, the cell may divide to form two daughter cells, each with the same characteristics as the original cell. These in turn may grow and divide. Thus, a many-celled organism grows not only by the increase in size of its individual cells but also by the increase in number of cells by **cell division** or cell multiplication. Growth of the organism may continue by a combination of these two processes until a certain size limit is reached, when the organism stops growing.

Reproduction

If life is not to perish from the earth, all living things must give rise to others of their kind before they die. Thus all plants and animals have the power to produce new individuals closely resembling the parents. This is called reproduction—a process which takes place sometime in the life cycle of the organism or at some period between its birth or generation and its death. There are two general types of reproduction: **asexual reproduction,** which is a relatively simple process, and **sexual reproduction.**

In asexual reproduction new animals and plants may arise by fragmentation of the parental body. The following two examples will serve to illustrate asexual reproduction. In **fission,** the parent divides into two new individuals and loses its identity. This process is characteristic of the lowest and simplest organisms (Figs. 133 and 148). We are most familiar with **budding** in plants, but it is found

also in animals. In budding, the parent retains its individuality, and the offspring, taking control of a portion of the parent protoplasm, separates from the parent (Figs. 134 and 148).

In sexual reproduction the organism forms specialized cells called **sex cells** or **gametes** (*gamein*—to marry). These gametes are usually dissimilar in size, the female gamete or **egg** being much larger than the microscopic male gamete or **sperm.** The union of a male and a female gamete forms a new cell, the **zygote** (*zygotes*—yoked), which is the first stage in the life cycle of a new individual.

Irritability

Another characteristic of living protoplasm is its peculiar inherent capacity to receive and respond to stimuli. A **stimulus** is any change, in the external or internal environment of the organism, which evokes a response. Now it has already been pointed out that the process of metabolism must go on in protoplasm or death will result. This means then that in order to live the organism must have an environment which affords an adequate supply of food and water as well as certain other favorable conditions such as temperature, humidity, light, water currents, chemicals such as gases, and other excitants. Protoplasm, if irritable or sensitive, is evidently so affected by stimuli that temporary adjustments are made from time to time by either the whole or a part of the organism. Such adjustments or **responses** may result in movement from an unsuitable environment to one more favorable. Thus, if there is lack of oxygen in a certain pool, an aquatic animal may move to some other part of the stream. The response just described is movement. Other stimuli, such as the sight or the taste of food, may result in secretion by certain glands.

Again, the stimulus of light will cause the green plant to grow toward the source of light. This adjustment, which is brought about by the growth of the plant, affects only the stem and the leaves. Sometimes the stimulus may affect only the leaves, as in the oxalis and locust leaflets which apparently fold up at night.

From what has just been said we may infer that in plants, especially the higher plants, responses usually involve only some part of the organism. In animals, the responses more frequently involve the entire organism. For example, the entire earthworm retreats into its burrow when subjected to the light stimulus. In animals stimuli do not affect one region only but their influence is transmitted through the protoplasm from cell to cell and from region to region by specialized structures, such as nerve fibers. A response may occur in the

new region even though it is some distance from the original point of stimulation. However, no such special transmission structures as nerves have been demonstrated in plants.

Thus the property of irritability makes possible the adaptation or adjustment of the organism to its environment. Such changes are quite often advantageous and may result in new modifications in structure and behavior. When such adaptive changes can no longer be made because of a decrease in irritability or sensitivity, the result is death for the animal or plant.

Movement or Motility

We cannot close the general discussion of the characteristics of protoplasm without pointing out that spontaneous movement of the protoplasm is characteristic of plants and animals. In both plants and animals there is protoplasmic movement within the cell which undoubtedly assists in the distribution of food and the elimination of wastes. This intracellular movement of protoplasm, called **cyclosis,** can readily be observed in the cells of the water plant *Elodea.* In some of the lower animals and plants we find specialized protoplasmic hairlike structures called **cilia** and **flagella** by which the organism is propelled and drawn through the water. These structures also occur on the sex cells of certain plants and animals. Rhythmic movements of the cilia on the cells lining the windpipe maintain the flow of mucus over the walls toward the outside. The lowly ameba moves by means of **pseudopodia,** which are outpushings of protoplasm. The white blood corpuscles progress through the body by similar **ameboid motion.**

In the higher animals we find this inherent property of protoplasm more pronounced with consequent greater specialization. Accordingly, here are well-developed structures like legs, wings, and fins with such supporting structures as bones and cartilages moved by the contraction of certain specialized cells known as **muscles.** This capacity for movement is an essential adaptive mechanism in all animals, and its inception is explained by the characteristic motility of all protoplasm.

LIFE: ITS NATURE AND ORIGIN

Organic and inorganic matter. Although the sugars, fats, and many other chemical compounds obtained from animals and plants had long been known, it remained for Lavoisier (1743–1794) to show

that nearly all plant substances are made up of carbon, hydrogen, and oxygen. He also showed that, in addition to the three elements just mentioned, animal substances always contain nitrogen and sometimes sulphur and phosphorus. Today we know that other elements enter into the composition of protoplasm.

The peculiar composition of these compounds and the fact that they were more combustible than the so-called inorganic substances, like lead, iron, and salt, led to the belief that carbohydrates, fats, and proteins were made under the influence of some peculiar vital force. It was thought that they could be produced only by the living organism and that they reacted differently from the "mineral substances." This distinction between organic and inorganic material received its death blow in 1828, when Wöhler succeeded in synthesizing urea, an animal excretion, from ammonium cyanate, which is an inorganic compound. This synthesis showed that the influence of a living organism is not necessary for the production of the "organic substance" urea.

Since the time of Wöhler chemists have made many organic substances from inorganic materials. We have synthetic orange, vanilla, and other fruit flavors which never came from the actual fruit; synthetic perfumes; and synthetic drugs and gland extracts (thyroxin, adrenalin). Thus the supposed difference between vitalized and non-vitalized compounds apparently has disappeared.

Yet there is a difference between compounds and elements united and combined in a living organism and those same compounds uncombined, unintegrated, and non-related. Whether matter is alive or not depends upon the peculiar, intricate combinations of atoms and compounds, such as the proteins, carbohydrates, fats, salts, and the like, of which it is composed. It will be readily understood that living protoplasm is constantly changing, taking in materials from the environment, working them over, using them, and finally discarding them as wastes. Yet, in the process of material change, the living protoplasm, usually in the form of an organism, maintains its individuality until death. The living organism is like a whirlpool in a stream. It retains its identity even though its constituents are constantly shifting and changing.

This living protoplasm is irritable and adaptable, carries on metabolism, grows, is capable of spontaneous movement, and, finally, gives to organisms the ability to produce new individuals like themselves. This is life—an adjustment of internal relations to external conditions.

Origin of life. In the light of the conclusion that there is no sharp boundary between the organic and the inorganic world, and that all matter has the same general plan of structure and obeys the same general physical and chemical laws, it is of interest to consider how life began. One theory originally offered to explain the origin of life was the theory of **spontaneous generation** or **abiogenesis** (*a*—not; *bios*—life; *genesis*—birth). The adherents of this theory held that living things could form spontaneously from lifeless and inorganic matter. "Is there, in the inorganic world, a happy concourse of atoms that become chained together through the action of the sun's rays and other natural forces, so that a molecule of living matter is constructed in Nature's laboratory without contact or close association with living substance?" * Does life come only from pre-existing life, or can it come directly from inorganic matter?

From the time of Aristotle (325 B.C.) to A.D. 1668, the theory of spontaneous generation was accepted by practically everyone. It was erroneously alleged yet firmly believed that under the influence of the sun's rays the mud and slime of ponds and streams transformed into frogs, toads, and eels (Fig. 14). Dewdrops transformed into grasshoppers, bees, and ants. The recipe for the production of mice was to place some cheese and old cloth in a vessel and in due time they would be transformed into mice. In Egypt mice supposedly had their origin in the mud of the river Nile. Sir Thomas Browne, who was inclined to doubt some of these acts of creation, was flayed for his disbelief by Alexander Ross, in these words:

"So may we doubt whether in cheese and timber worms are generated, or if beetles and wasps in cow-dung, or if butterflies, locusts, shell-fish, snails, eels, and such life be procreated of putrefied matter, which is to receive the form of that creature to which it is by formative power disposed? To question this is to question reason, sense, and experience. Or if he doubts this let him go to Egypt, and there he will find the fields swarming with mice begot of Nylus to the great calamity of the inhabitants."

One of the reasons for this belief in what, to our minds, is pure foolishness was the fact that no one subjected the theory to experimental tests, i.e., scientific analysis. However, in 1668, an Italian, Redi, decided to test scientifically the theory that meat would transform into worms. This experiment was done in a simple and homely

* William A. Locy, *Biology and Its Makers*, p. 227, Henry Holt and Company, New York.

fashion by placing meat in flasks. Some of the flasks he covered with paper, others with a kind of gauze, and others he left uncovered. The flies, attracted by the odor of the decaying meat in the jars, came and laid their eggs in the exposed meat in the uncovered jars and on the gauze covering other jars. In time the eggs hatched, and the meat in the uncovered flask became a crawling mass of maggots. No maggots appeared in the meat in the covered jars, but the eggs

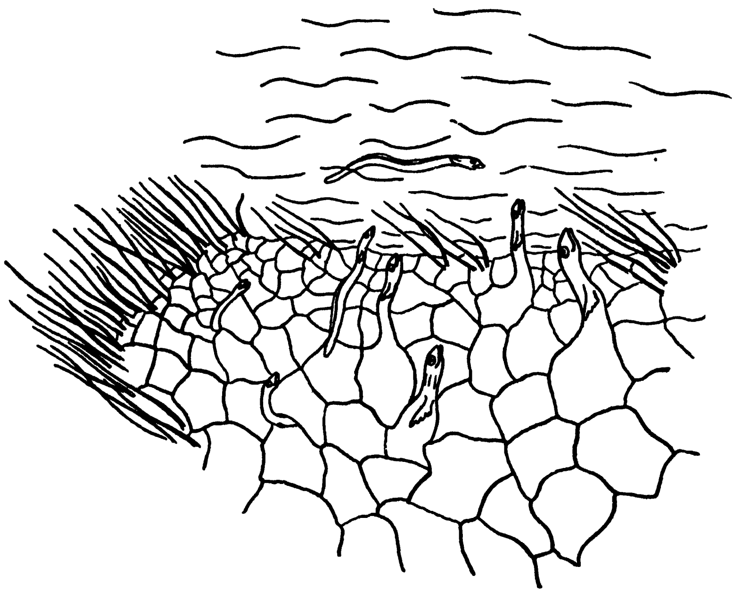


FIG. 14. Spontaneous generation. An illustration of the old belief that mud transforms into eels.

laid on the gauze hatched into maggots. Thus Redi demonstrated that the maggots came from the insect eggs and not from meat. Redi made other important and interesting experiments, but it is recorded of him that **"with acute scientific analysis he never allowed his conclusions to run ahead of his observations."**

The investigation begun by Redi was carried on by later experimenters. A scientist named Leeuwenhoek had improved the microscope, and in 1687 he discovered a new world of minute animals and plants, including the bacteria. These minute living organisms appearing in apparently pure water, in fruit juices, and in sterile foodstuffs were now thought to be the first organisms produced whenever inorganic material was changed through natural agencies into organized living things. Spallanzani (1777) found out that, if meat

broth was boiled for about an hour and then sealed in a vessel, no life appeared in the broth.

In 1864, Pasteur, a French chemist, showed conclusively that boiled or sterilized fruit juices and other food materials would re-

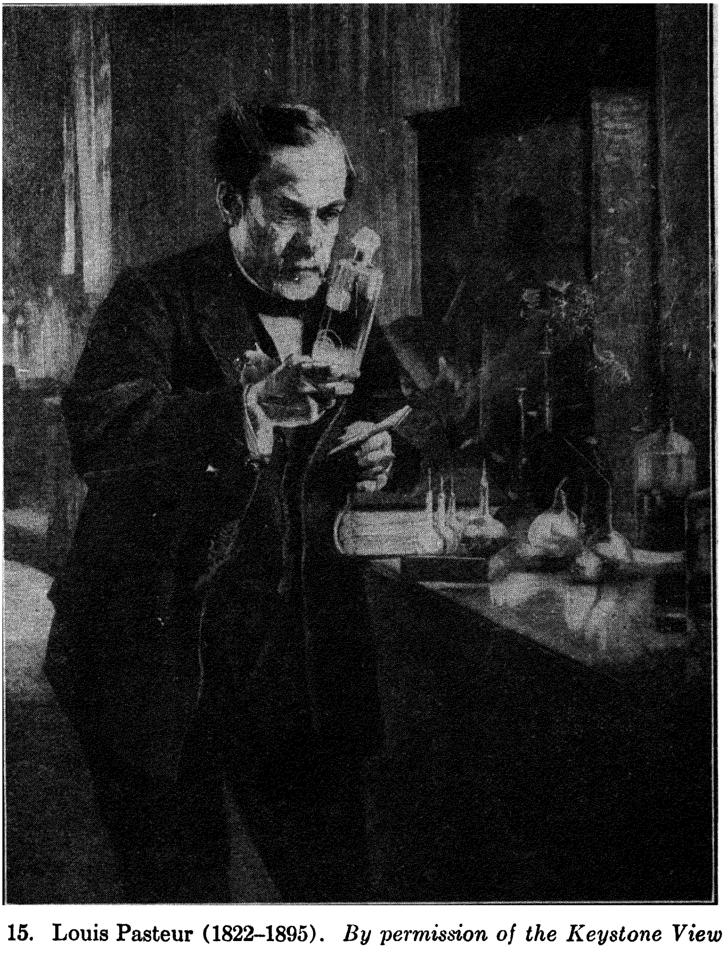


FIG. 15. Louis Pasteur (1822–1895). *By permission of the Keystone View Co.*

main unchanged if kept free from contamination by germ-laden air. He made a special flask with two necks, one of which had a double curve and a small opening. After an infusion had been poured into the flask the larger opening was sealed. The infusion in the flask was then boiled to kill all living things that might be in either the infusion or the flask. No dust particles carrying germs could get into the flask because of the curved neck provided with a liquid seal.

Regardless of how long these infusions were kept under these conditions, no microscopic organisms could be found in them. When his critics objected that boiling had so changed the infusions that they could no longer support life, Pasteur broke open some of the flasks containing the previously boiled and sterilized infusions, thus admitting air. Very shortly these solutions swarmed with living organisms. This result was Pasteur's reply to his critics, for it proved that the boiled infusions could support life. This experiment clearly showed that living organisms could not arise spontaneously but that they entered with the air only when the flasks were broken. Tyndall, an English physicist, also produced scientific evidence disproving the theory of spontaneous generation.

Thus the theory of spontaneous generation or abiogenesis, namely, that living things or life can come from inorganic or lifeless material, was succeeded by the theory of **biogenesis,** which maintains that all life must come from some pre-existing life—*omne vivum e vivo*. However, many scientists think that there may have been and still is some sort of spontaneous generation which connects the inorganic with the organic world. It is possible that life may begin in particles too small to be seen even with the microscope. The discovery of viruses seems to offer proof of the existence of such particles. However, little is known of the structure of viruses, and as has already been pointed out they may be inanimate particles of matter. As suggested by a well-known biochemist, "if these units are proteins, the gap between the living and the non-living has been almost bridged." It is possible that the earliest organisms which exhibited life characteristics resembled bacteria. Certainly thus far the evidence we have seems to indicate that the life found in the oldest rock strata must have been bacterial.

CHAPTER III

METABOLISM. HOW IS FOOD MANUFACTURED? THE FOOD-MANUFACTURING PLANT

As we have already observed, life is dependent upon a continuous flow of energy transformations, and, since the energy content of living organisms in turn depends upon the food supply, we can readily understand why the maintenance of life requires an adequate consumption of food. Our need of food is such a commonplace experience that we seldom think of the ultimate source from which it is derived, yet this is one of the most fundamental considerations in the entire field of biology. Therefore we should be interested in knowing something about the source of this food, its nature, and how it is produced.

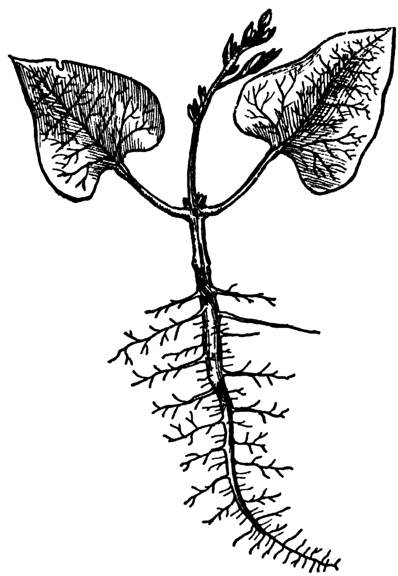


FIG. 16. A young bean plant showing the vegetative organs, leaf, stem, and root.

The food supply of practically all living organisms, both plants and animals, is manufactured by green plants—real factories. If we are to acquire any appreciable knowledge of this whole process of food manufacture it will be necessary for us to study one of these factories where the various operations take place. There are many kinds of food factories, such as an oak tree or garden bean, but a study of the machinery and organization of any one plant will enable us to understand better how it manufactures food.

ORGANIZATION OF THE PLANT

A plant such as a tree or common garden bean has three different kinds of vegetative organs, viz., **leaf, stem,** and **root** (Fig. 16). An

organ has been defined as a group of tissues working together to perform some specific function or functions. Each of these organs of the plant has its own peculiar activities, which are so correlated that they contribute jointly to the growth and development of the organism as a whole.

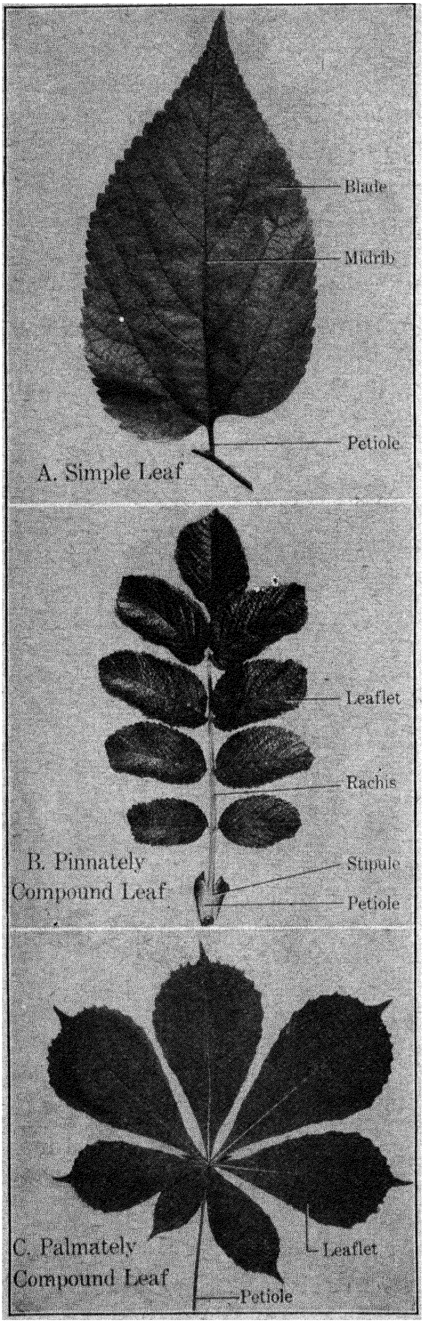


FIG. 17. Types of leaves. *Photographs by H. Lee Dean.*

THE LEAF

Ordinarily a leaf possesses a **blade,** the flat expanded part, which has a skeletal framework of numerous branching **veins** (Fig. 17). In many leaves, extending from the base to the tip of the blade, there is a large central vein called the **midrib.** Usually the blade is attached to the stem and supported by a little stalk called the **petiole.** In some plants, for example, bananas and grasses, the petiole has the form of a **sheath** that closely clasps the stem. In some plants, however, the leaves have no petiole, the leaf blades being attached directly to the stem. Leaves of this sort are said to be **sessile** (*sessilis*—sitting). In some plants, such as the pansy and the rose, outgrowths called **stipules** occur on each side of the base of the petiole where it is attached to the stem.

The elm leaf has a single blade and is therefore called a **simple leaf** (Fig. 17). In some plants, such as the bean, rose, and locust, the leaf blade is represented by a

number of small, separate **leaflets** borne on a common axis. Such a leaf is called a **compound leaf** (Fig. 17). If the leaflets are borne at the top of the petiole, as in buckeye, the leaf is **palmately compound** (*palma*—hand); if they are borne laterally on an extension of the petiole called the **rachis,** the leaf is **pinnately compound** (*pinna*—feather). Some plants like yarrow and many members of the parsley family have leaf blades that are more or less cut and dissected; other leaves such as those of the tulip tree and white oak are merely lobed.

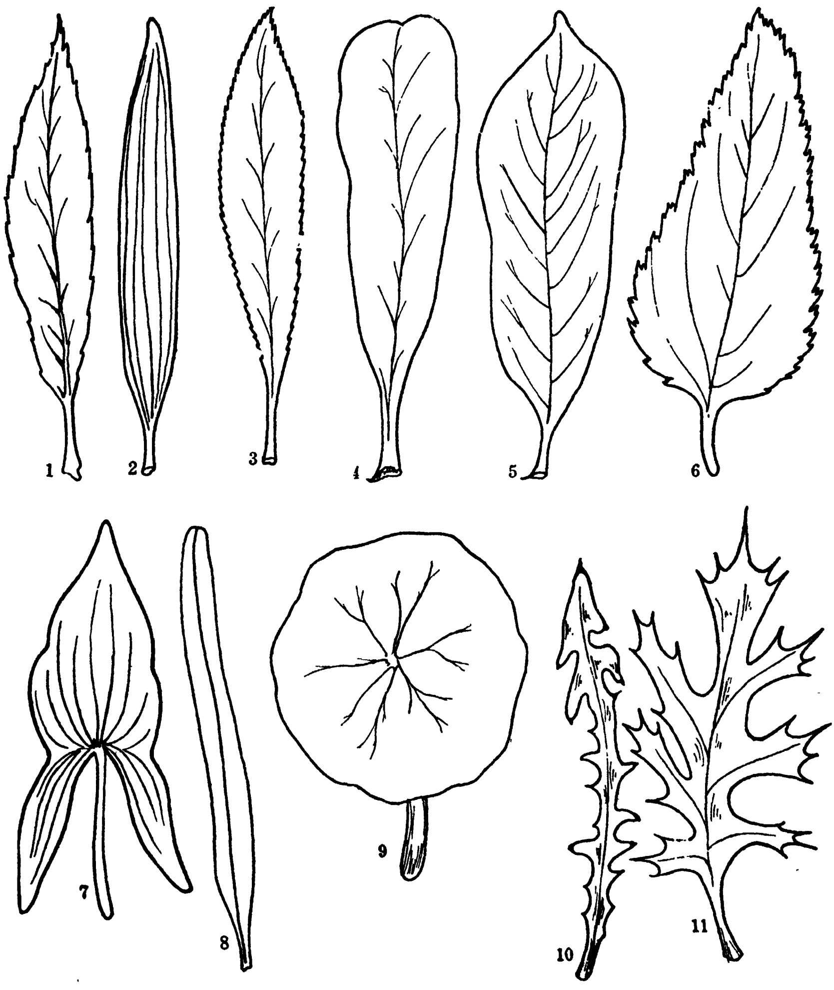


FIG. 18. Illustrations of leaf patterns: 1, lanceolate; 2, linear; 3, oblanceolate; 4, cuneate; 5, oblong; 6, ovate; 7, sagittate; 8, linear; 9, peltate; 10, cut; 11, lobed.

There is a wide range of variation in the shape, size, and texture of leaf blades (Fig. 18). The gigantic, pinnately compound leaves of certain palms attain a length of fifteen feet or more, whereas some of the leaves of water stitchwort may be very little larger than the head of a pin. Leaves are so variable in form that a special vocabulary has been developed to designate the different shapes of the blades, tips, bases, and margins. There are also marked differences in the texture of leaves, some being hard and leathery and

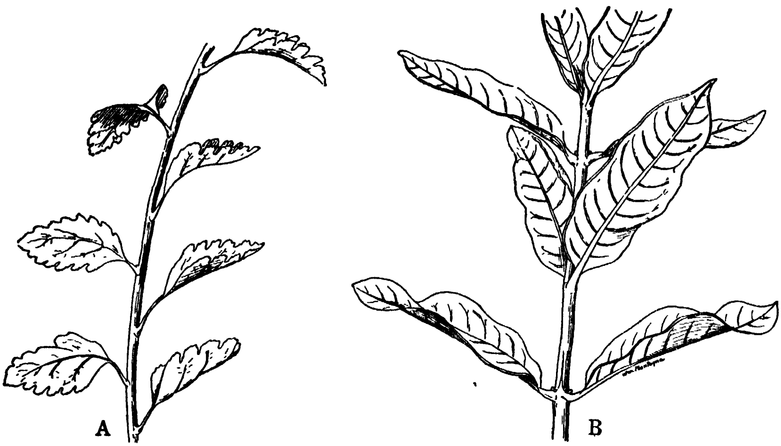


FIG. 19. Leaf arrangement: *A*, alternate; *B*, opposite.

others extremely delicate. Some plants have tough, fibrous leaves, and the leaves of others are tender and succulent, i.e., they contain much water. Leaves also vary greatly in thickness, some being very thick and fleshy and others so thin as to be almost translucent.

Arrangement and orientation of leaves. Leaves do not originate at just any point on the stem but arise in a definite order at regions called **nodes** (Fig. 19). If only one leaf occurs at a node the arrangement is **alternate;** if two leaves are present at the same node on different sides of the stem the arrangement is **opposite;** if three or more leaves occur at the same node the arrangement is known as **whorled.** The individuals of any given species usually have a definite type of leaf arrangement, independent of environmental conditions.

Leaf arrangement is determined by heredity and is affected very little, if at all, by factors in the environment of the plant. On the other hand, the orientation of leaves on the branch is the result of their response to light, which is such that each leaf is shaded as little

as possible by adjacent leaves. Thus the foliage of the entire plant receives the greatest possible amount of light. Light tends to retard growth, and consequently the cells on the illuminated side of the petiole grow more slowly than those on the opposite side. This differential growth causes a bending and often a twisting of the petiole that brings the broad surface of the blade into a position where it receives the maximum amount of light, a condition that may be observed in the leaves of many shrubs and trees.

As a result of the adjustment of the leaves to light they are often so mutually fitted in the space they occupy as to form what is known as a **leaf mosaic.** Vines growing on walls are illuminated from one side only, and consequently the leaves are frequently displayed in very attractive mosaic patterns (Fig. 20). Mosaics are also formed by those plants that bear their leaves at the level of the ground, like dandelion, plantain, and chicory, and because of their circular pattern are called **rosettes** (Fig. 20). Some plants like prickly lettuce and the rosin weed of the prairies have their leaves turned edgewise in a north and south plane extending through the stem from bottom to top. Thus they are well lighted during the early and late hours of the day, but are protected from the more intense light of midday. Such plants are called **compass plants** (Fig. 20). Grasses and plants of similar habit usually have more or less erect leaves so that there is the least possible interference with light reception and each leaf receives the maximum amount of diffuse light. The fact that, in general, the leaves of plants are so arranged that they receive the greatest possible amount of light indicates that light must play an important role in the life of the plant.

The structure of the leaf. We have already learned that protoplasm is organized into cells, cells into tissues, and tissues into organs. The outermost layer of cells in the leaf forms the **epidermis** (*epi*—upon; *dermis*—skin) (Fig. 21). Generally these cells secrete a waxy substance forming a **cuticle** on the outside of the epidermis. The epidermis on one or both surfaces of the leaf is perforated by numerous small pores called **stomas** (*stoma*—mouth). Each stoma is surrounded by two **guard cells.** The walls of a guard cell are not uniformly thickened, and these are usually the only cells of the epidermis that contain green plastids. By changing their shape the guard cells increase or decrease the size of the stomatal opening, which permits a direct exchange between the internal atmosphere of the leaf and the air outside.

Beneath the upper epidermis of the leaf there is usually a layer of elongated cells, compactly arranged with their long axes perpen-

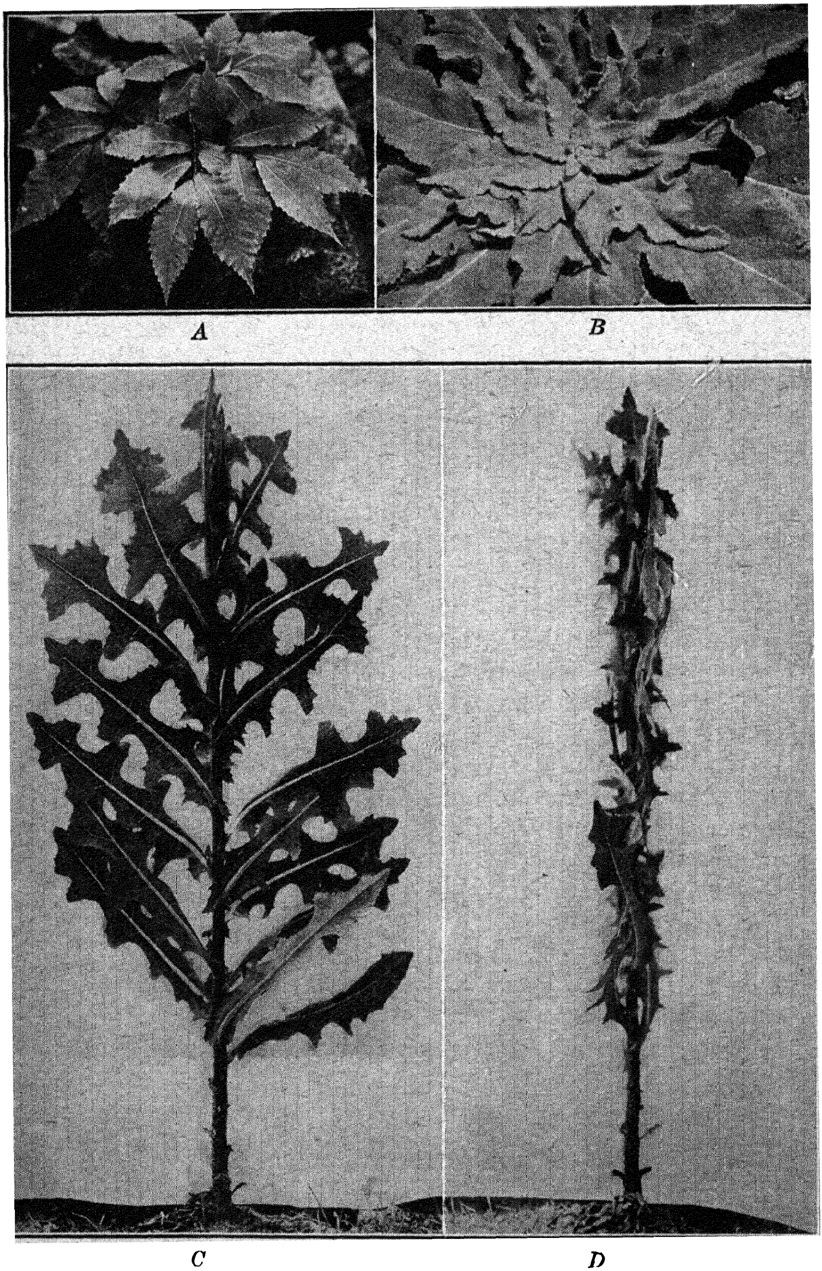


Fig. 20. *A*, leaf mosaic of chestnut; *B*, rosette of mullein leaves; *C* and *D*, prickly lettuce plant showing the compass plant arrangement of leaves; *C*, plant viewed from the western side; *D*, the same plant viewed from the northern side.
Photographs A, C, and D by W. E. Rumsey; B by H. L. Dean.

dicular to the plane of the leaf, forming the **palisade layer** (Fig. 21). Between the palisade layer and the lower epidermis is the **spongy tissue** of the leaf. The spongy tissue is composed of very irregular cells so loosely arranged as to form a large number of **intercellular spaces** that provide for an ample supply of air within the leaf. In the spongy tissue next to the palisade layer are the **veins,** which are made up of elongated cells of two kinds. One kind forming the

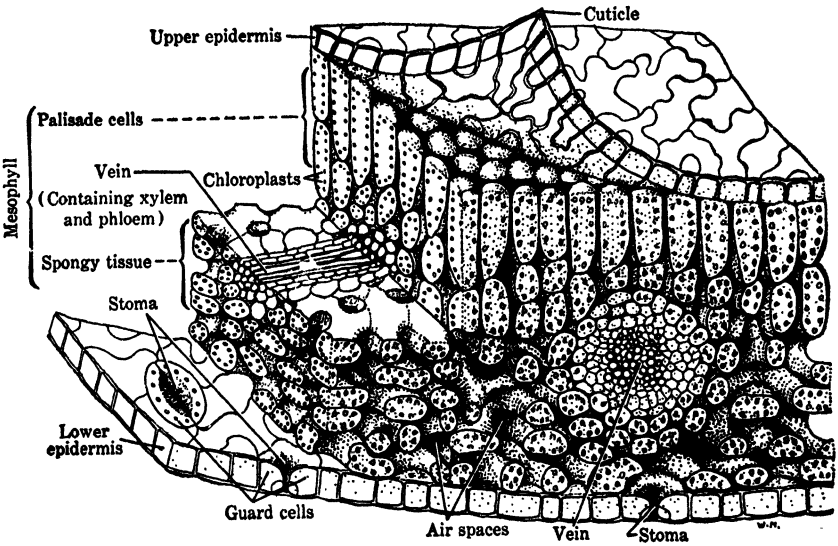


FIG. 21. Anatomy of the leaf.

water-conducting tissue, or **xylem,** is found in the upper part of the vein; the other forming the **food-conducting tissue,** or **phloem,** lies in the lower part.

The palisade tissue and the spongy tissue collectively form the **mesophyll** (*mesos*—middle; *phyllon*—leaf). The tissues of the mesophyll are readily influenced by environmental factors and consequently show wide variations in different plants. Leaves of water plants usually have no palisade tissue, and many plants exposed to intense sunlight and having a minimum supply of water often have little or no spongy tissue. But regardless of the varying nature of the palisade and spongy tissues, as seen in different plants, one feature is common to both and quite constant in all leaves everywhere, viz., the presence in the cells of a green pigment called **chlorophyll** (*chloros*—green; *phyllon*). This chlorophyll occurs in definitely organized bodies of specialized protoplasm called **chloroplasts.** They

are usually found at the periphery of the cytoplasm (Fig. 21). Chloroplasts are generally spherical or elliptical, but they are capable of changing their shape and position in response to external factors, particularly light. Although the presence of chlorophyll in the leaves is responsible for the dominant green color of vegetation throughout the world, we should remember that it may occur in any part of the plant that happens to be subjected to a prolonged exposure to light.

We have previously noted that tissues are the cell fabrics of which organs are composed. We can recognize the following tissues in the leaf: the epidermis, the mesophyll, the water-conducting tissue, the food-conducting tissue, and the mechanical or supporting tissue that partially or completely surrounds the veins. Tissues made up of more or less unspecialized cells having thin walls, and rich in protoplasm, are designated **parenchyma.** When such cells contain chloroplasts the tissue may be called **chlorenchyma** (*chloros*—green; *enchymein*—to pour into). The water-conducting tissue of the veins is made up of thick-walled, elongated cells that have lost all or nearly all their protoplasm. Aside from their conductive function, the veins form a skeletal framework for the mechanical support of the more succulent parenchyma of the leaf. These leaf tissues are coordinated in their functioning, and each has its role in the work of food manufacture, as we shall see after we have considered the other parts of this food factory.

The Stem

The stem is usually thought of as the erect aerial axis of the plant, but in many plants it lies prostrate on the ground and in others it is entirely underground. But, regardless of what position it may have, the stem always supports the leaves. In some plants, such as cactus and asparagus, leaves are wanting or reduced to small scales (Fig. 22). In these plants the stem develops chlorophyll and manufactures the food. Stems may be either simple or branched, and the general form of the plant varies accordingly.

A stem begins its development in what is known as a **growing point** (Fig. 23), and all subsequent elongation depends upon the activity of this growing point. The growing point is made up of unspecialized cells capable of indefinite division. Such unspecialized tissue is called a **meristem** (*meristes*—a divider). Here new cells are continually being formed by **cell division.** The **enlargement** and subsequent **differentiation** of these new cells give rise to the tissues

that appear in the mature stem. These three initial stages—cell division, cell enlargement, and cell differentiation—are involved in the growth, reproduction, and development of all living things, both plants and animals. As the stem develops it becomes organized into **nodes,** which are the regions where all lateral structures such as leaves and branches normally arise, and **internodes,** the regions be-

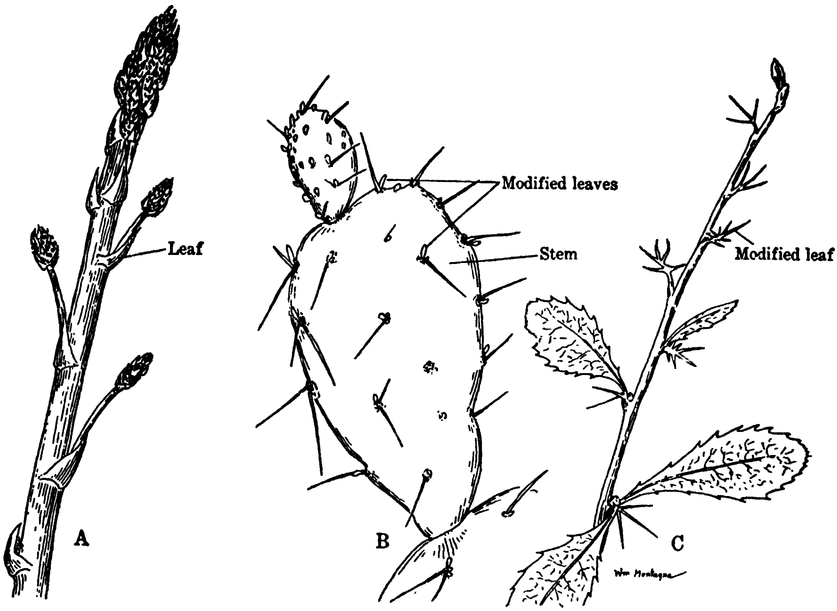


FIG. 22. *A,* scale leaves of asparagus. *B,* small fleshy leaves of cactus. *C,* leaves of barberry (*Berberis vulgaris*) showing gradation from true leaves with spiny margin to much-reduced thorny outgrowths.

tween the nodes where elongation takes place (Fig. 23). On a young twig the position of the nodes is indicated by the location of the leaves, or, if they have fallen, by the **leaf scars** that remain. The **axillary bud** that later gives rise to a branch occurs in the **axil** of the leaf, which is the region above the base of the petiole, between it and the stem. The outside of the young stem is usually flecked with small, light-colored spots called **lenticels.** These are accumulations of loosely arranged, corky cells at points where stomas existed during an earlier stage in the stem's development.

Underground stems. There are four types of underground stems, and on all of them the leaves produced below the level of the ground are colorless and reduced to mere scales. The **rhizome, or rootstock,**

is a horizontal, more or less elongated, underground stem such as is seen in Solomon's seal and the common iris (Fig. 24). The **tuber** is a rather short, fleshy, usually horizontal, much-thickened enlargement frequently formed at the end of a slender rhizome. The Irish potato is a tuber whose "eyes" are groups of lateral, axillary buds,

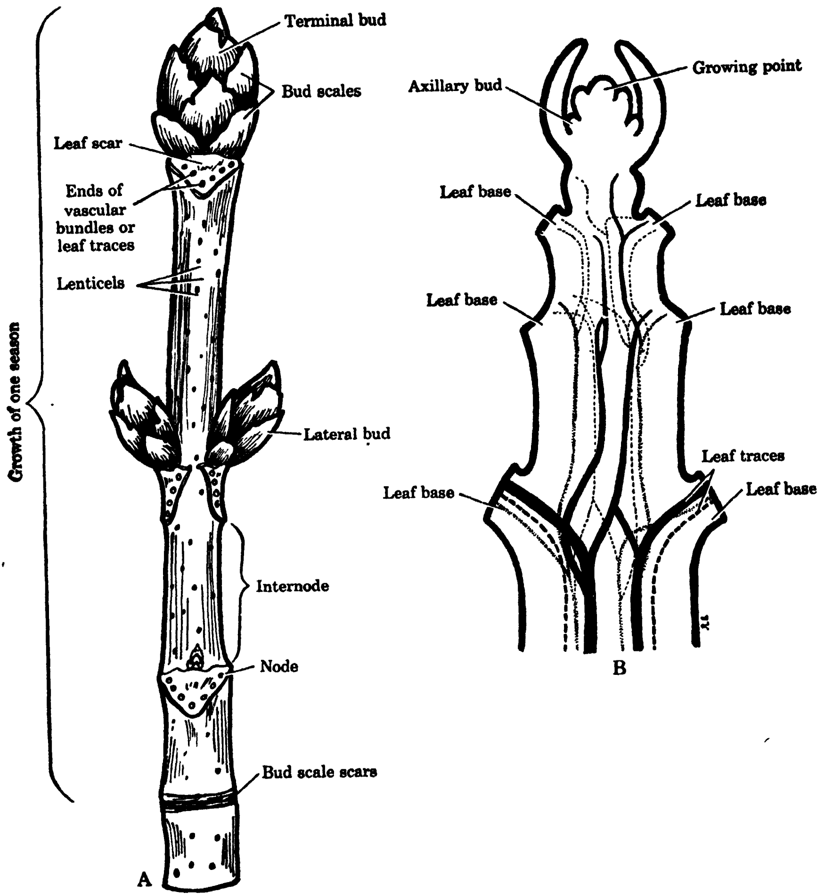


FIG. 23. *A,* external features of a twig (buckeye). *B,* diagram of stem of Clematis showing the growing point and, in perspective, the vascular bundles (leaf traces) which pass out into the leaves at the nodes. *B, modified from Holman and Robbins, "Textbook of General Botany."* (*After Nägeli.*)

each group having an adjacent, arching leaf scar that forms the "eyebrow." A **bulb** such as the common onion is an erect underground stem reduced to a mere **plate** surrounded by fleshy, overlapping leaf bases. The **corm,** such as gladiolus and the Indian turnip, is an erect, much-shortened underground stem that is not invested by fleshy leaf

bases. In all underground stems a considerable amount of food materials is stored, which makes it possible for many of them to reproduce new stems and leaves in an incredibly short period.

Structure of the stem of a dicotyledon. There are two groups of flowering plants called respectively dicotyledons and monocotyledons. Subsequently, we shall learn more about these two groups, but since each has its characteristic stem structure, we shall now

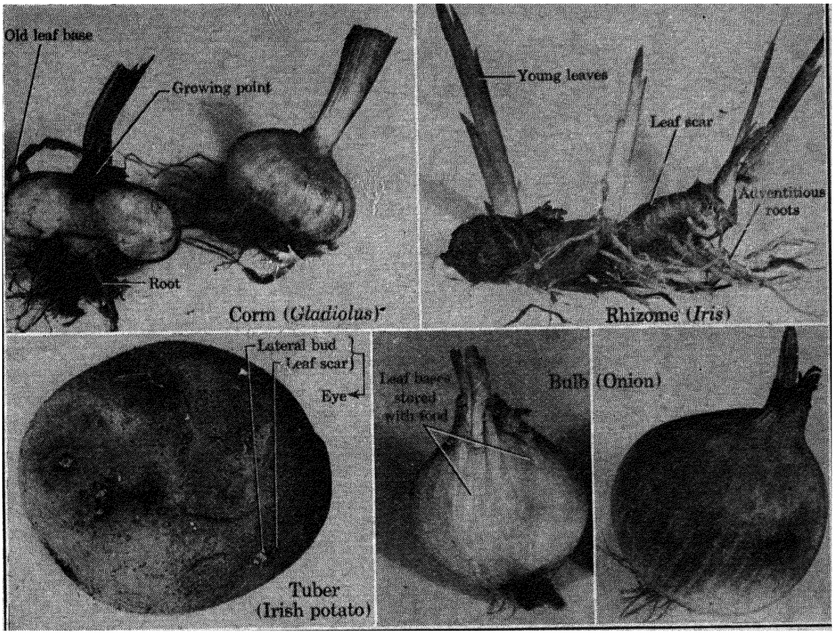


FIG. 24. Types of underground stems. *Photographs by J. S. V. Allen.*

consider the two types, studying first the dicotyledonous stem like that of the bean plant or maple tree (Fig. 25). The internal structure of the stem is quite complex, and therefore we shall emphasize merely the fundamental structural plan.

In a very young stem an **epidermis** forms the outermost tissue. At first this epidermis contains stomas surrounded by guard cells similar to those found in the epidermis of leaves. Beneath the epidermis is the **cortex** made up of parenchyma, the cells of which may contain chloroplasts. Lying just inside the cortex is the cylinder of conductive tissues called the **stele,** at the center of which is a slender cord or column of parenchyma called the **pith.**

The stele consists of **vascular bundles** arranged in a ring surrounding the pith. These bundles may be separated by radiating plates

of parenchyma called **primary pith rays,** extending from the pith to the cortex. The vascular bundle is so called because it contains elongated, tubular conductive cells. Vascular tissue, as the name implies, whether found in plants or in animals, and whatever its

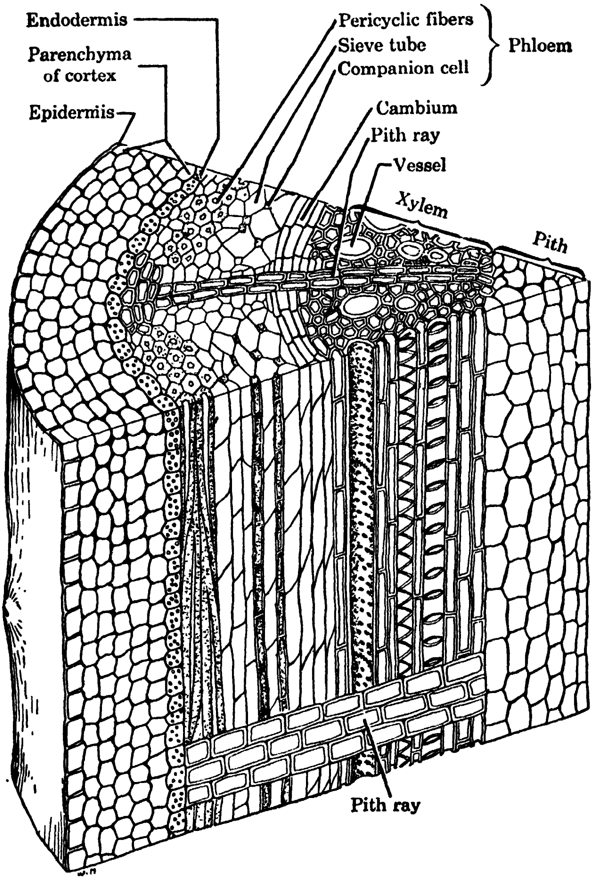


FIG. 25. Diagram of portion of a woody dicotyledonous stem.

nature, is always concerned with the conduction of liquids. The inner portion of the vascular bundle contains the conductive vessels (water-conducting tissue), **wood fibers,** and **wood parenchyma.** These elements collectively make up the **xylem** or wood. The outer portion of the vascular bundles contains **sieve tubes** (food-conducting tissue), **pericyclic fibers,** and parenchyma. These elements collectively make up the **phloem.** Between the xylem and the phloem is a region of **meristem** called the **cambium** (Figs. 25 and 26). The

divisions of cambial cells take place in such a way that new cells are added both on the inside, that is on the side toward the pith, and on the outside of the cambium. The subsequent growth and differentiation of these cells increase the amount of xylem and phloem, respectively, and thus increase the diameter of the stele. The growth of the stele is largely responsible for the increase in the

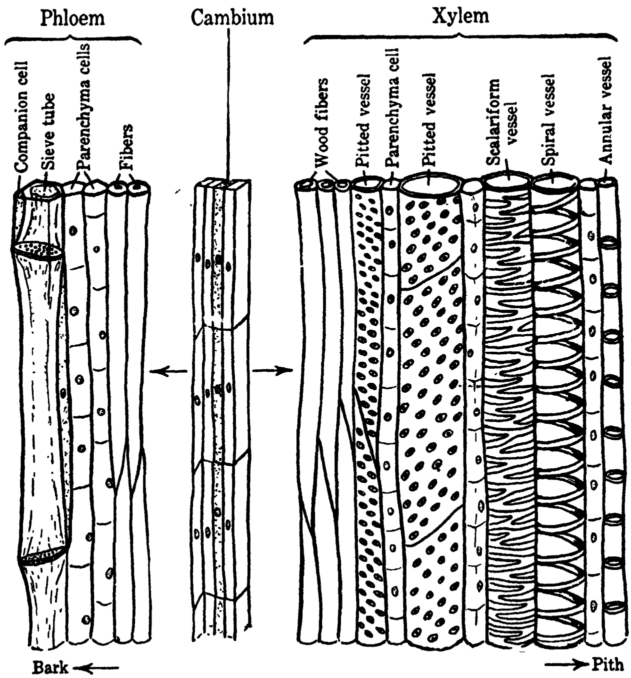


FIG. 26. Diagram showing division of cambial cells and tissue elements derived from the cambium.

diameter of the stem. Vascular bundles in which a cambium occurs are called **open bundles.** Thus we see that in a dicotyledonous stem the vascular bundle is made up of xylem, cambium, and phloem.

In woody stems, such as those of shrubs and trees, the xylem cells produced during spring and early summer are larger and have thinner walls than those produced later in the season. This difference between xylem cells formed early and those formed late in the season gives rise to the appearance, in cross section, of concentric **growth rings** (Fig. 27). In general, one growth ring is formed each season, and therefore a count of these rings reveals the approximate age of the tree.

Weather conditions have a marked influence on the width of growth rings, and by a study of the relative thickness of these rings one can ascertain when in the life of the tree favorable or unfavorable conditions were encountered. In New Mexico are the famous Pueblo Bonito ruins whose age until recently was purely a matter of conjecture. Then Dr. A. E. Douglass began a careful and systematic study of the growth rings found in the timbers of these ruins. By comparing the growth-ring records found here with those obtained previously in a study of living trees, he was able to determine with extreme nicety and unquestionable accuracy that Pueblo Bonito was founded in A.D. 700.

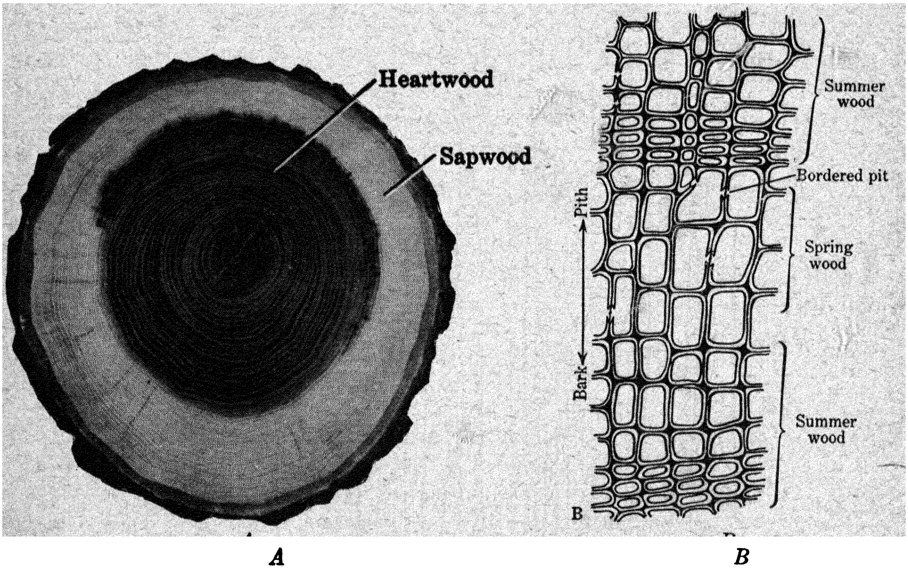


FIG. 27. *A,* cross section of a stem, showing growth rings, heartwood, and sapwood. *Photograph by H. Lee Dean. B,* cross section of xylem showing spring wood and summer wood.

The xylem formed by the cambium remains alive for a few years, but eventually the cells lose all their protoplasm and the xylem becomes dead tissue, forming the **heartwood.** Thus the woody portion of a tree trunk consists of a cylinder of dead wood called the heartwood—once live xylem—surrounded by a cylinder of living wood called the **sapwood** (Fig. 27).

The fundamental unit of water-conducting tissue is called a **tracheid,** and greatly enlarged and otherwise modified conductive elements are known as the **tracheae** or **vessels** (Fig. 26). In addition to the tracheids and tracheae, the xylem contains wood fibers and little-differentiated wood parenchyma. Wood fibers, cortical fibers, and other fibers. together with all other cells having greatly thick-

ened walls, small lumens, and no protoplasm, are the structural units of the mechanical or supporting tissue. The thickened walls of xylem cells contain a complex substance called **lignin** that gives them their woody character.

The food-conducting tissue consists of a series of cell complexes called **sieve tubes** and **companion cells** (Fig. 26). The sieve tube is made up of a row of cells separated by perforated or sieve-like end walls that suggested the name. The companion cells are elongated cells that were formed by an early division of the sieve-tube mother cell. They are closely associated with the sieve tubes, whose activities they are thought to regulate. Phloem, then, contains sieve tubes, companion cells, phloem parenchyma, and pericyclic fibers.

At an early period in the history of man, when he exchanged his animal skins for garments made of vegetable fibers, the flax plant assumed an important place in the list of useful plants. Linen fabric made from fibers of the flax plant was probably the first textile produced by man. Since that early period, many uses have been found for plant fibers, and a number of plants have been discovered that yield valuable economic fibers. The linden tree is sometimes called "basswood," which is a corruption of bast wood. It is so called because of the bast fibers of the inner bark which were once used for bag strings and small ropes. Common binder twine may be made from sisal, hemp, or manila fibers (Fig. 28).

If the entire vascular bundles are used as a source the fiber is called "hard" fiber, but if only the bast fibers are used it is known as "soft" fiber. New Zealand flax, sisal from Yucatan and Central America, and manila from a species of banana plant grown in the Philippines are examples of hard fibers. Ramie from a species of the nettle family, flax, hemp, and jute are all examples of "soft" fibers. Hemp is much used in making cordage, bagging, and webbing, and the ravelings of hemp rope are used under the name oakum to calk the seams of wooden boats and the joints of iron pipe, also as packing in pumps, engines, and other machinery. Jute is used in making gunny sacks, burlaps, and binder twine. It is about two-thirds as strong as hemp, of the same weight, but less durable. In 1940 the total value of vegetable fibers of all kinds imported into the United States amounted to $29,427,681.

The cortical cambium and bark. While the stem is increasing in diameter, through the activity of the cambium of the stele, significant changes take place in the outer part of the cortex (Fig. 29). Certain of the cortical cells beneath the epidermis assume meristematic functions and thus form a cambial ring in the cortex. The new cells formed on the inside of this cambium develop into cortical parenchyma, and those formed on the outside develop corky walls, giving rise to **cork tissue.** As the stem continues to increase in diameter, the epidermal cells eventually die and are sloughed off. Thus the epidermis finally disappears, and the corky tissue becomes the only

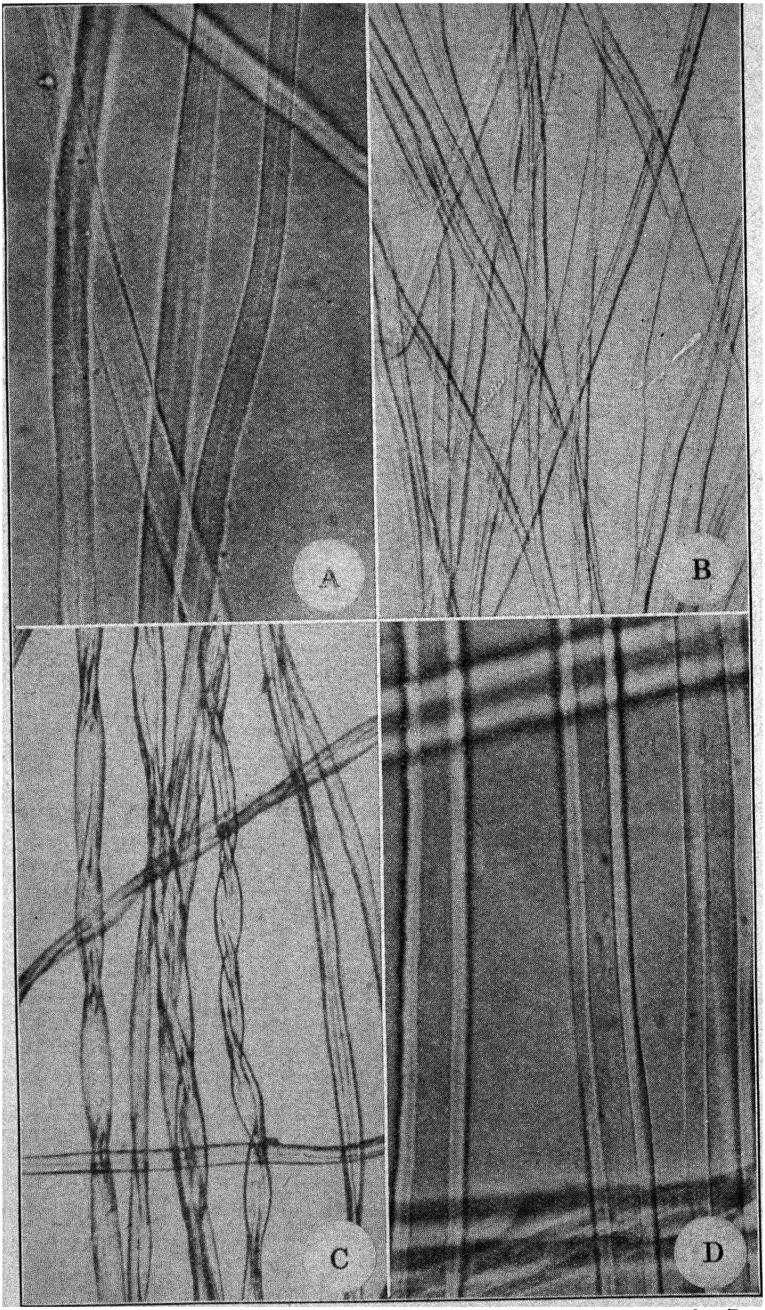


FIG. 28. Photomicrographs of plant fibers. *A*, bast fibers of basswood. *B*, wood fibers of black locust. *C*, cotton fibers. *D*, wood fibers of red maple. *Photomicrographs by H. Lee Dean.*

investing, protective layer of the cortex. As the stem increases in diameter, successive new cork cambiums develop, and thus new areas of cork are produced at different periods during the growth of the tree. The dead corky tissue forms the outer bark, which is often wrongly thought of as the entire bark of the tree. The term bark actually refers to all the tissues of the stem extending from the cambium of the stele outward and includes two parts, the living part between the cork cambium and the cambium of the stele, and the

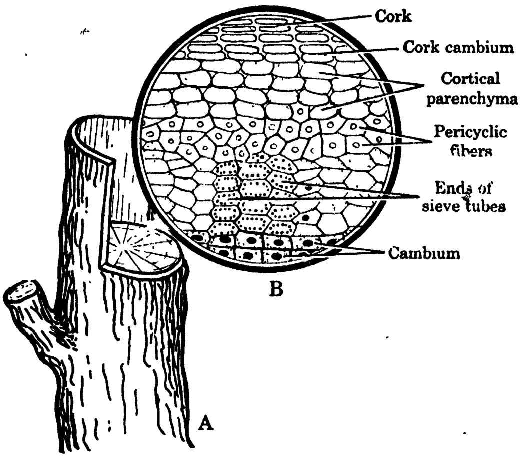


FIG. 29. *A,* portion of stem showing bark separated from the wood in the region of the cambium. *B,* cross section of bark.

dead outer portion which is being continuously sloughed off or exfoliated.

In Portugal, Spain, and other Mediterranean regions there grows an evergreen oak known as the cork oak. This tree has an unusually vigorous cork cambium which produces the cork of commerce. When the tree is about 25 years old the first cork is removed. This is called virgin cork and has no value. About 10 or 12 years later the marketable cork is removed, and thereafter at intervals of 12 to 14 years, depending upon the vigor of the tree, successive crops of cork bark are harvested during the life of the tree, usually a period of 150 years. The average yield of a single tree at the time of each cutting is about 45 pounds. Cork trees are now being grown experimentally in different parts of California, and it is already apparent that the climatic and soil conditions are quite as favorable as those of Spain and Portugal for the successful production of cork. All our trees produce cork, but no species is known that produces it in such quantities or of such quality as does the cork oak.

Structure of the stem of conifers and monocotyledons. The structural plan of the stem of the cone-bearing plants (conifers), such as

pine, hemlock, and spruce, is precisely the same as that of the dicotyledonous stem, only there are no tracheae (vessels) in the xylem, the water-conducting tissue being made up of tracheids alone. Since

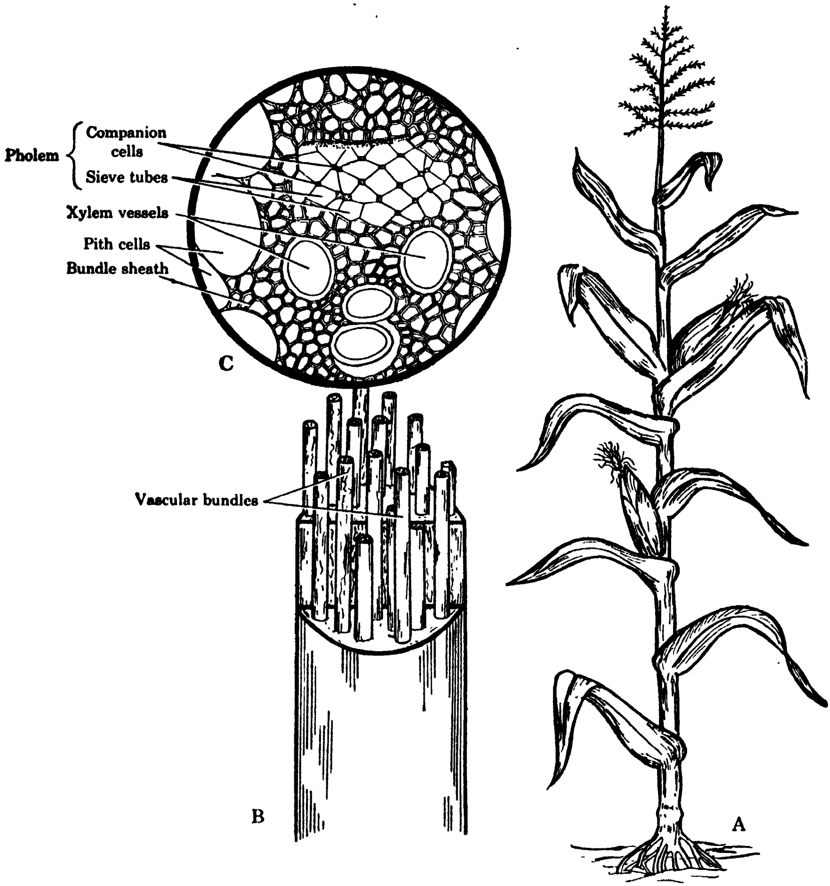


FIG. 30. *A,* habit sketch of a monocotyledonous plant (corn). *B,* a portion of the stem showing arrangement of the vascular bundles. *C,* cross section of a vascular bundle.

no vessels are present no large pores can be seen when a cross section of a conifer stem is observed. Such wood is said to be non-porous. This is one of the principal distinctions between the so-called softwoods (conifers) and the hardwoods. In the monocotyledonous stem, such as is found in grasses, lilies, and orchids, the bundles are not arranged in a ring but are scattered irregularly throughout the pith (Fig. 30). Each bundle is surrounded by a group of more or

less thick-walled cells forming a **bundle sheath.** There is no cambium in the bundle; therefore no new cells can be formed, and consequently, after the original cells have reached their full size, there can be no further increase in the diameter of the stem. Such bundles are called **closed bundles.** These are characteristic of monocotyledons just as open bundles with cambium are characteristic of the dicotyledons.

The following table presents a comparison of monocotyledonous and dicotyledonous plants. We shall learn more about some of these characteristics in our subsequent study.

MONOCOTYLEDONS	DICOTYLEDONS
1. Have scattered bundles.	1. Usually have bundles arranged in a ring about the pith.
2. Have closed bundles (no cambium).	2. Have open bundles (cambium).
3. Have bundle sheath.	3. Have no bundle sheath.
4. Usually have parallel-veined leaves.	4. Have netted-veined leaves.
5. Have closed venation.	6. Parts of the flower mostly in fours
6. Parts of the flower usually in threes or sixes, never in fives.	5. Have open venation. or fives.
7. Embryo with a single cotyledon (seed leaf).	7. Embryo with a pair of opposite cotyledons (seed leaves).

Herbs, shrubs, and trees. Plants with little or no woody material in their stems, such as plantain, beans, and grass, are called **herbs.** Low woody plants are called **shrubs,** and taller woody plants are called **trees.** It is sometimes exceedingly difficult to distinguish among these groupings. Such a classification of plants based on stem character is purely arbitrary. But regardless of its size, position, or structure, the stem is always the medium of conduction between the roots and leaves.

THE ROOT

The root has its origin in a **growing point** that forms at the root end of the plant axis. This first root is the **primary root,** and its lateral branches are called **secondary roots.** If the primary root persists throughout the life of the plant, it is called a **tap root** (Fig. 31). Such tap roots as the radish, turnip, and dandelion often store food in considerable quantities and become large and fleshy. All roots arising from stems or leaves are called **adventitious roots,** and in a large number of plants the entire root system is made up of such roots. In many plants, such as wheat and most grasses, adventitious roots arise at the lower nodes of the stem and form a **fibrous root**

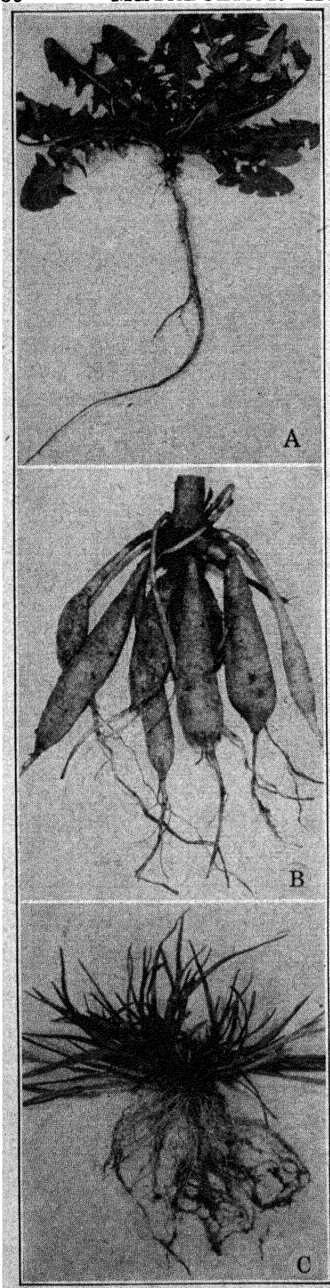


FIG. 31. *A*, taproot (dandelion); *B*, fascicled roots (dahlia); *C*, fibrous roots (grass). *Photos by J. S. V. Allen.*

system. In such plants the primary root soon dies and disappears. In most prostrate stems, roots arise on the under side at the nodes and provide anchorage (Fig. 32). Now if such a stem is branched the older parts of the plant may die, and then each separate branch, thoroughly rooted in the soil, may continue to grow, giving rise to a new plant. It is obvious that the development of such adventitious roots is advantageous in increasing the number of individual plants and also in aiding plants to enter new territory.

Structure of the root. The structural plan of the root is quite similar to that of the dicotyledonous stem, but some differences are worthy of note (Fig. 33). An **epidermis** covers the young root on the outside, and beneath this is a **cortex** in the cells of which chloroplasts will appear if the root becomes exposed to light. The cortex surrounds the **central vascular cylinder** or **stele,** which in most roots has no shaft of pith at its center. In the first vascular bundles formed (primary structure) the **phloem** and **xylem** are found in separate bundles so arranged that two phloem groups are always separated by a xylem group, and vice versa (Fig. 34). This alternation of the phloem and xylem bundles is called **radial arrangement** to distinguish it from the **collateral arrangement** found in stems, where, as we have already observed, phloem and xylem lie on the same radius, forming parts of one and the same bundle. Such radial arrangement of bundles in the primary structure is characteristic of primitive stems and of all roots. When the cambium appears and new tissue is formed (secondary structure) the subsequent arrangement of the secondary

phloem and xylem is precisely the same as that found in the stem (Fig. 34).

The root tip and root hairs. At the extreme tip of the root is a covering of loosely arranged and disintegrating cells that comprise the structure known as a **root cap** (Fig. 33). As the cell walls of this tissue break down and soften, the surface of the root cap becomes somewhat slimy, thus enabling the root to penetrate the soil more easily. Next to the root cap is the terminal meristem or **growing point** which, through active cell division, adds new cells to the root cap, which is constantly dying and sloughing off on the outside.

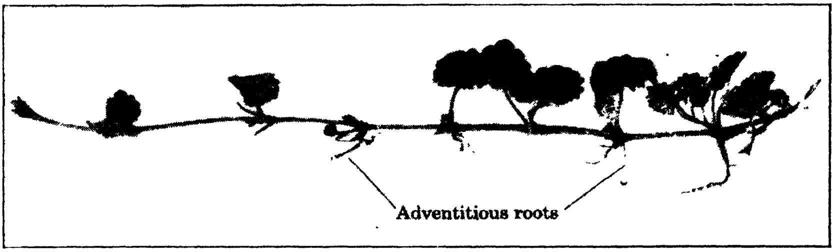


FIG. 32. Adventitious roots of ground ivy. *Photograph by J. S. V. Allen.*

These new cells enlarge, forming a growth region that causes elongation and pushes the end of the root farther into the soil. Just back of the region of elongation are the mature tissues of the root, where there is no further increase in length. The outer surface of this region of the root is covered with a dense growth of **root hairs** that give it a whitish fuzzy appearance. Because of the presence of these root hairs, this region of the root is called the **root-hair zone** (Fig. 33).

Root hairs are extremely delicate tubular outgrowths of the epidermal cells (Figs. 35 and 42), ranging from a fraction of a millimeter to 7 or 8 millimeters in length. Although some absorption takes place through the epidermis of young roots, the root hairs are the chief agents concerned with absorption. There may be more than 400 of them on a single square millimeter of epidermal surface. Owing to such great numbers, root hairs may increase the root surface as much as twenty times, thus greatly increasing the absorbing area. Usually, root hairs remain alive and active for only a few weeks at most. As they die a new crop of root hairs forms on the new portion of the root.

Origin of lateral roots. The outermost region of the stele is made up of one or more layers of unspecialized cells known as the **pericycle,** a very important region of the root where all lateral branches arise.

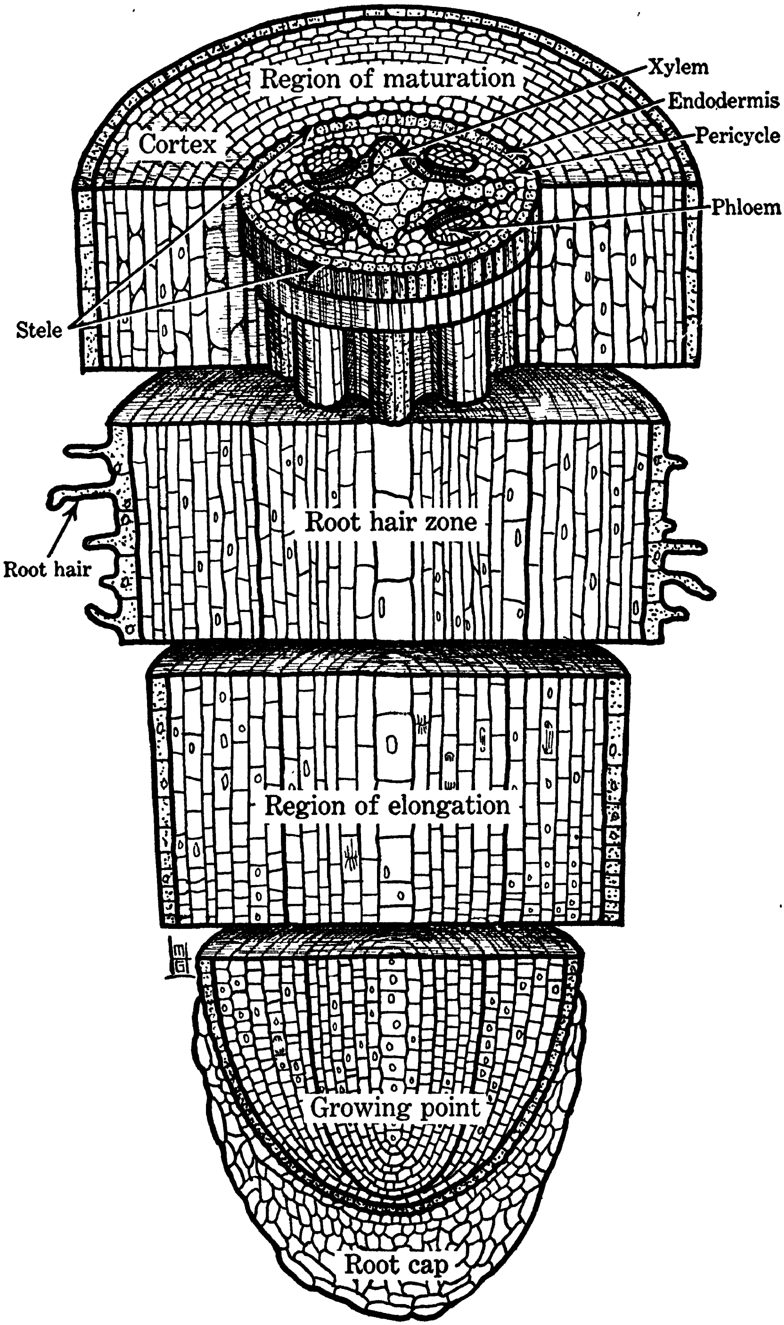


FIG. 33. Diagram of longitudinal section of a young root.

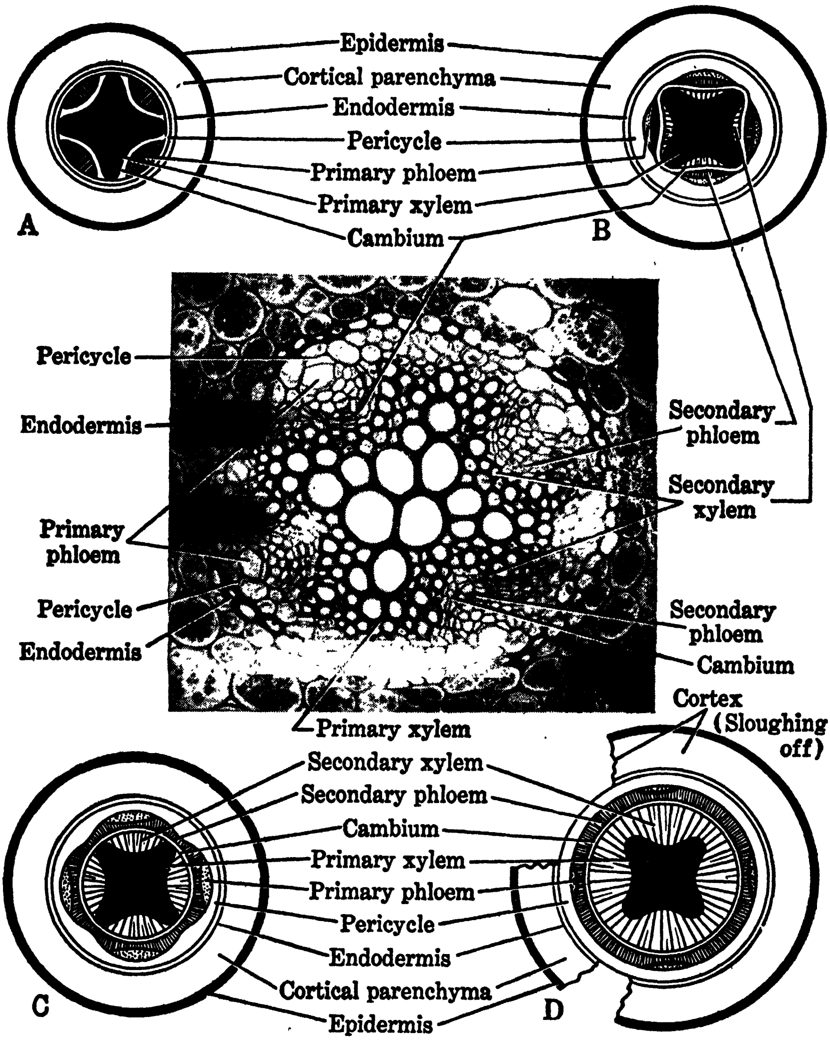


FIG. 34. Diagrams *A–D* showing successive developmental stages in the primary structure of a young root (*Ranunculus acris*). Photomicrograph showing later secondary structure. *Photomicrograph by H. Lee Dean.*

At some point in the pericycle the cells begin to divide, giving rise to a localized meristem or growing point. The enlargement produced by the accumulation of newly formed growing cells pushes out into the cortical parenchyma. This enlargement elongates, pushing its way across the cortex to the epidermis, where it finally breaks through as a lateral branch or secondary root (Fig. 36). Since roots, unlike

stems, are not organized into nodes and internodes, lateral roots have no orderly arrangement such as leaves and branches have.

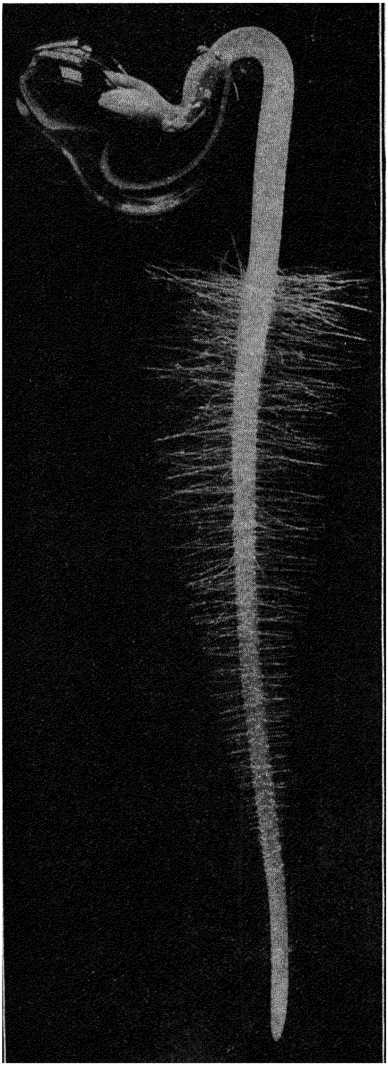


FIG. 35. Photograph of root hairs. *Holman and Robbins, "Textbook of General Botany." By permission of John Wiley & Sons.*

Development of cork. As roots grow older a cork cambium develops, usually in the pericycle, and through its activity a corky layer is formed similar to that produced in stems (Fig. 29). When this corky layer is formed the primary cortical tissue and epidermis die and are gradually sloughed off, leaving the old roots covered by a thick layer of dead, corky tissue.

The media in which roots grow. When we think of a root we generally have in mind one that grows in the soil, i.e., a **soil root.** But we know from general observations that not all roots are of this kind. There are plants whose roots grow in water—**aquatic roots,** and still others whose roots grow in the air —**aerial roots** (Fig. 37).

Willow trees growing along stream margins usually produce great masses of aquatic roots, and where willows or poplars border streets, their roots often grow into sewers and drains, eventually filling them completely with a great accumulation of small aquatic roots. Such trees thus become a public nuisance, and many cities and towns have ordinances that demand the cutting of all poplar trees along the streets and forbid the planting of these trees anywhere within the corporation limits. Aerial roots may be seen on the English ivy (Fig. 37) and on the common poison ivy where they serve as "hold fasts" that anchor the vine to its support. They are also abundant on tropical orchids and bromelias that grow perched on the branches of tall trees. Such perched plants are called **epiphytes** (*epi*—upon; *phyton*—plant). In the corn plant there are adventitious roots that arise from the lower nodes of the stem. At the outset

these are aerial roots, but, as they grow downward and enter the soil, they become typical soil roots. Such roots are often called "prop roots" (Fig. 37). Some plants like the dodder grow upon other plants, from which they procure all their food. Such a plant is known as a **parasite** (*para*—beside; *sitos*—food)

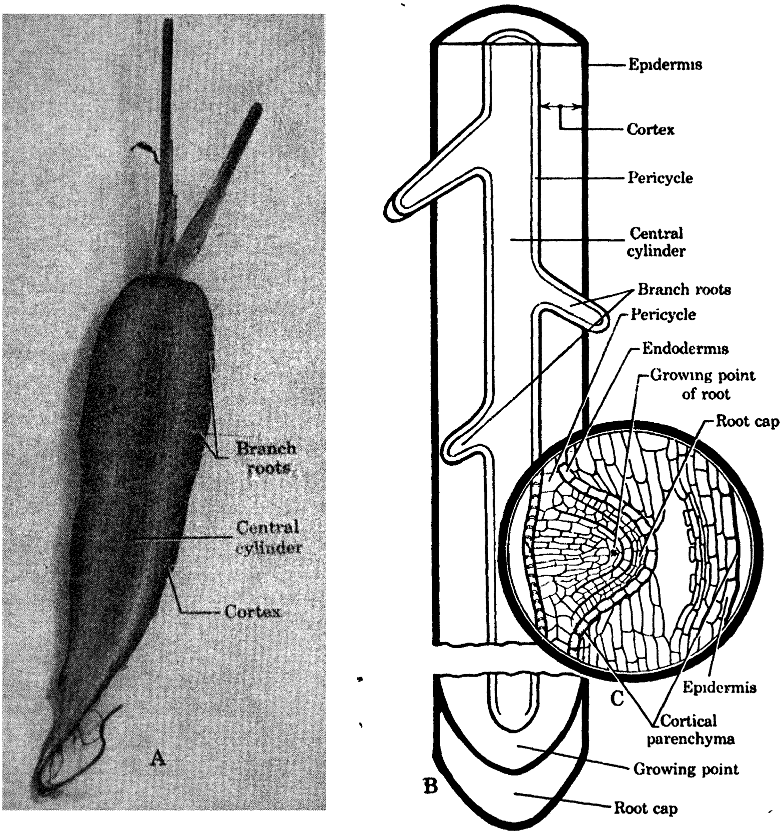


FIG. 36. **Origin of secondary roots.** *A,* longitudinal section of a carrot showing gross structure, and origin of branch roots. *B,* diagram showing general anatomy of root and origin of secondary roots. *C,* Drawing showing beginning of a young secondary root. *Photograph by J. S. V. Allen.*

and the plant on which it grows is its **host.** The parasite sends specialized roots called **haustoria** (*haustor*—drinker) into the tissue of its host, and these modified roots take up the food the parasite needs (Fig. 37).

Function of roots. Anchorage, absorption, and conduction are the fundamental functions of roots. The root system of a tree becomes very large and supports a tall stem bearing a great crown of foliage. In such a plant we can readily recognize the importance of roots as

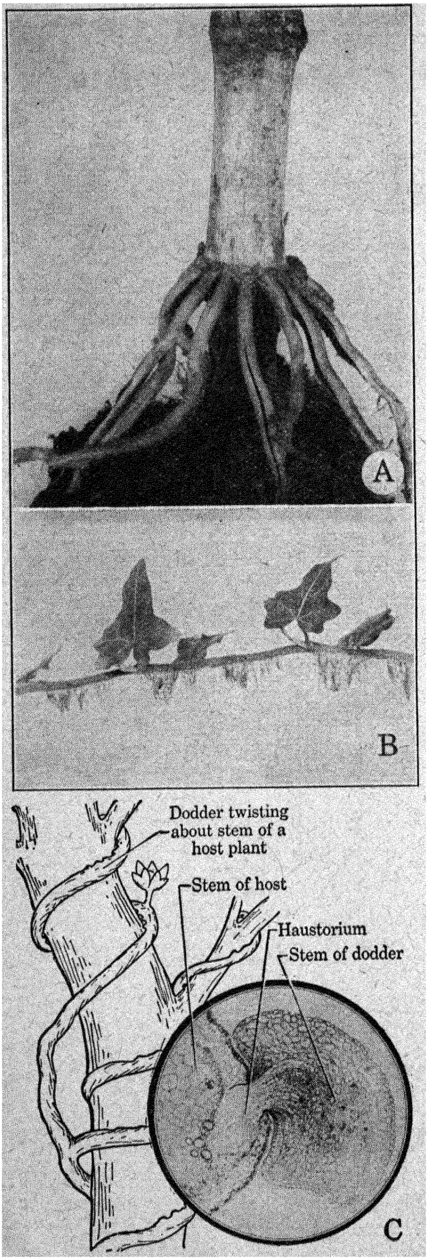


FIG. 37. Adventitious roots: *A*, prop (corn); *B*, aerial (English ivy); *C*, haustorial (dodder). *A and B by J. S. V. Allen. C by H. Lee Dean.*

anchors, always keeping the plant most advantageously related to its supply of raw materials. As we shall see later, the ultimate branches of the root are especially adapted as absorbing structures that obtain the raw materials necessary in food manufacture and other processes of the plant. Roots are also important as storage organs where great quantities of reserve food are accumulated for plant use. Some plants like the sweet potato have great economic value because of the food materials stored in their roots. Many drugs are obtained from the roots of plants which are therefore valuable commercially. Roots, particularly adventitious roots, are of great importance in the natural and artificial propagation of plants, as may be seen in the growing of the cuttings of coleus or geranium.

Roots in relation to the life cycle of plants. The life cycle of a plant is the entire series of changes in its development from a seed to the stage when it produces seed of its own. In certain desert plants that appear only during the very brief rainy season the whole life cycle may be completed within a period of two weeks, and then the plants die. The life cycle of the common chickweed is completed in such a short time that several generations may be produced in a single year. Many species, as

the garden bean, complete their life cycle within the period of a growing season. All such plants, that grow from seed, produce flowers and seeds, and then die, thus completing the entire life cycle within one year's time, are known as **annuals.** Plants like the turnip and beet, during the first season, develop a fleshy root and crown of leaves at the top of an exceedingly short stem. Early in the following summer these stems elongate rapidly and flowers and seeds are formed, after which the plants die. In these plants two years are required for the completion of the life cycle; therefore they are called **biennials.** All plants that live longer than two years are known as **perennials.** When we speak of perennials we are naturally inclined to think of shrubs and trees, but it is necessary for us to remember that all those plants whose root systems remain alive for more than two years are also perennial plants, even though the aerial parts die each year. Thus we see that the classification of plants into annuals, biennials, and perennials depends primarily upon the length of life of the root systems.

If wheat (winter wheat) is sown in autumn the plants will live through the winter and complete their life cycle during the following summer. On the other hand, if wheat (spring wheat) is sown in the spring the cycle is completed during the summer and the plant is now an annual. Thus we see that the time of planting may determine whether the plant is to be classified as an annual or biennial. When some annuals and biennials are grown in a greenhouse they become perennials. Certain perennials of the south where the climate is uniform behave as annuals when removed to regions where there is an alternation of winter and summer temperatures.

Continuity of the vascular system. We have now completed our study of the organs of the plant, and we have observed that conductive tissues (xylem and phloem) are found in each of these organs. It is very necessary that we should recognize the continuity of these tissues throughout the entire plant. The xylem found in the root continues through the stem, through the petiole of the leaf, and into the leaf blade, where it forms a part of the veins. These veins gradually decrease in size until they finally end in a single tracheid. The phloem of the veins extends through the petiole into the stem and continues on into the roots. Thus we see that the vascular bundles form a continuous vascular system that extends from one end of the plant to the other (Fig. 43).

The organization of the tissues in leaf, stem, and root is such that each one of these organs has its specific work to do, and the function of each is so coordinated with that of the others as to contribute to the work of the plant as a whole. Now that we have learned something of the machinery in the food-manufacturing plant, we are ready

to see how this machinery works and what each separate part does in the manufacturing process.

HOW THE RAW MATERIAL IS SECURED AND TRANSPORTED

Having made our examination of the machinery in this food factory—the green plant—we shall now try to ascertain how this machinery operates to secure and transport the raw materials used in the making of food. First we shall have to consider four important physical processes involved in the movement of materials into the plant, through the plant, and out of the plant. These physical processes are: **solution, diffusion, imbibition,** and **osmosis.**

Solution. We have already noted that water forms a large part of protoplasm, and it is highly significant that most substances—solids, liquids, and gases—can pass into or out of the cell only when dissolved in water. This at once suggests the importance of water as a common solvent in the operations of the food-manufacturing machinery of the plant. Whatever the state of matter may be there is an inherent tendency of the molecules to separate, and this tendency is opposed by their cohesion or mutual attraction. Therefore, when two or more substances are brought together they become intermingled. Solids, such as lead and gold, intermingle but slowly, whereas liquids and gases mix very rapidly. This intermingling of molecules or particles of different substances is called solution. A **solution** may be defined as a mixture of substances so intimate that they cannot be mechanically separated, as, for example, by filtration. A solid dissolved in a liquid is spoken of as the **solute.** The dissolving liquid is the **solvent.**

Diffusion. In a previous section it was stated that the molecules of a substance are in constant motion. The distance between molecules is greatest in the gaseous state, less in liquids, and least in solids. Therefore in gases the cohesive force holding the molecules together is much less than in either liquids or solids, and consequently the molecules of gases have the greatest freedom of movement. If a gas like carbon dioxide is released in a room, the molecules will pass rapidly through the atmosphere until they are uniformly distributed. In other words, a gas tends to fill all available space. If a crystal of potassium permanganate is placed in a glass of water, the coloring of the water adjacent to the crystal indicates that molecules of the substance are passing out into the water, i.e., among the molecules of the water (Fig. 38). This movement will continue until all the water in the glass is uniformly colored, or in

other words until the molecules of the solute (potassium permanganate) and those of the solvent (water) are equally distributed. This movement of molecules through a medium is called **diffusion,** and the direction of the movement is always away from the place where they are most abundant. Gases and solids dissolved in water may move by diffusion into the cell, through the cell, and out of the cell, the direction being determined by their relative concentration which sets up what is known as a diffusion gradient.

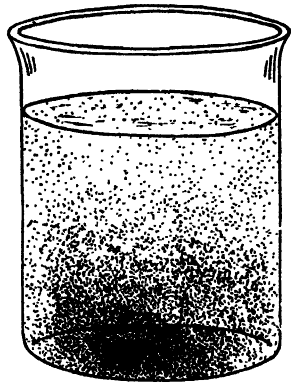


FIG. 38. Diagram illustrating the diffusion of dissolved particles through a liquid.

Imbibition. When placed in water, a piece of gelatin or a small block of wood will swell. The swelling is caused by the diffusion of water molecules into the gelatin or wood, thus forcing apart the molecules of the penetrated substance. This is a special form of diffusion called **imbibition.** Cell walls in plants take up water in this manner. In fact, most organic substances possess this property. It is a common observation that when dry seeds are placed in water they swell as the result of imbibition.

Osmosis. If an animal membrane, such as a piece of bladder, is tied over the mouth of a thistle tube, which is then immersed in water, the water will diffuse through the membrane into the tube and continue to rise until it has reached the level of the water outside the tube (Fig. 39). When this point is reached diffusion continues, but the amount of water now diffusing out of the tube is the same as that entering the tube; consequently the level inside remains even with the level of the water outside. If a little sugar is dissolved in the water in the thistle tube, the level of the liquid in the tube will begin to rise above the level of the liquid outside. It is obvious that more water is now passing through the membrane into the tube than is moving out of the tube into the vessel. This may be partly explained by the fact that the invisible pores of the membrane which readily allow water molecules to enter are, for the most part, too small to permit the passage of the larger sugar molecules. Consequently the outer surface of the membrane is in contact with more molecules of water tending to pass through it into the tube, whereas on the inside the surface of the membrane is partially covered by sugar molecules which block the passage so that fewer water mole-

cules can diffuse outward. The presence of sugar dilutes the water in the tube, and consequently the water on the outside of the membrane is more concentrated. Therefore, in compliance with the general law of diffusion, the water moves from the place of its greater concentration to the region of its lower concentration. The sugar molecules also tend to obey this law but are prevented from doing so by the membrane, most of the pores of which are too small to

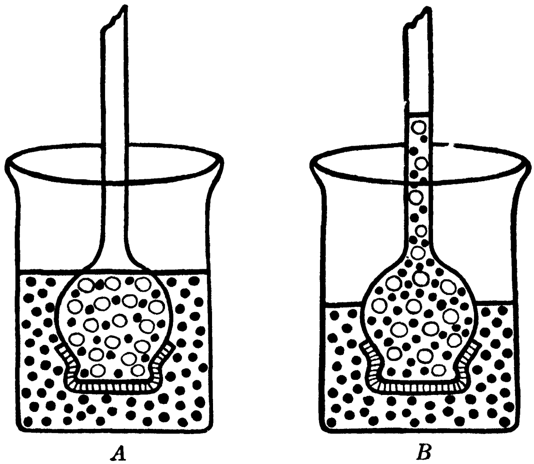


FIG. 39. Diagram representing the passage of water through a differentially permeable membrane. In *A,* the movement of water molecules through the membrane into the more dense solution within the thistle tube is beginning to exceed the outward movement of water molecules. In *B,* after some time has elapsed, this greater inward movement of water molecules has diluted the solution as is shown by its greater level in the thistle tube.

transmit the sugar molecules. Moreover, the sugar molecules have a great affinity for the water molecules and therefore tend to hold them inside the tube (Fig. 39).

Differentially permeable membranes. Any membrane that permits the passage of a given substance is said to be permeable to that substance. A membrane that permits the passage of one substance but retards or prohibits the passage of another substance is called a **differentially permeable membrane.** The piece of bladder is a differentially permeable membrane because it permits the free passage of water molecules but transmits very few of the sugar molecules dissolved in water. All living cell membranes are differentially permeable. The diffusion of substances through differentially permeable membranes is called **osmosis.** The movement of the material through

the membrane into the cell we call **endosmosis** (*endon*—within; *osmos*—pushing). Movement of material through the membrane out of the cell we call **exosmosis** (*ex*—without).

Osmotic pressure. If, in the above experiment, we close the upper end of the thistle tube, the rising column of water will compress the air in the enclosed tube. The greater the concentration or the amount of the sugar in solution, the more rapid will be the rise of the water column and the greater the pressure exerted by it. Pressure developed by diffusion under these conditions is called **osmotic pressure.** We can also think of osmotic pressure as that pressure which would be just sufficient to prevent the diffusion of the molecules into the cell. This is a very simple explanation of osmotic pressure, and, although some factors involved are not accounted for, it gives us some appreciation of how osmosis works in the cells of plants.

The plant cell, an osmotic machine. In the plant cell, the plasma membrane, and in some cells the cell wall itself, is differentially permeable. The central vacuole found in most mature plant cells contains a watery solution of sugars, salts, organic acids, and other substances. Therefore, the cell is an osmotic apparatus, and water will move into or out of it, the direction of the motion being determined by the diffusion gradient. If the cell is in contact with water or other cells containing water, there will be a movement of water into the cell if the concentration of the solution within the vacuole is higher than that of the solution on the other side of the plasma membrane. If this relation is reversed, water will diffuse out of the cell and the protoplast will draw away from the cell wall, contracting toward the center of the cell. This behavior is known as **plasmolysis** (*plasma*—form or mold; *lysis*—loosening) (Fig. 40).

If a plant cell is bathed in a concentrated salt solution, water molecules within the cell will pass out through the cell membrane into the salt solution. If the difference in concentration is small an equilibrium may soon be established and only a partial plasmolysis may result. Under more favorable conditions such a cell may recover its normal condition. If the concentration of the solution outside remains greater than that within the cell, exosmosis will continue until the cell becomes completely plasmolyzed, a condition from which there is no recovery. This gives us an explanation of how weeds are killed by the application of salt. Since the concentration of the salt solution is higher than that of the cell sap, the water moves outward, i.e., from the less-concentrated solution into the solution of higher concentration. At first sight, this seems to contradict the general law of diffusion, but such is not the case. The water mole-

cules themselves are more numerous in the solution of lower concentration (within the cell) and, therefore, they move from this solution to the more highly concentrated salt solution outside, where there are fewer water molecules. Therefore, as previously stated, the water molecules move from the region where they are more numerous, i.e., more concentrated, to the region where they are less concentrated. But, so far as the solution itself is concerned, this movement of water must necessarily take place from the less-concentrated solution where

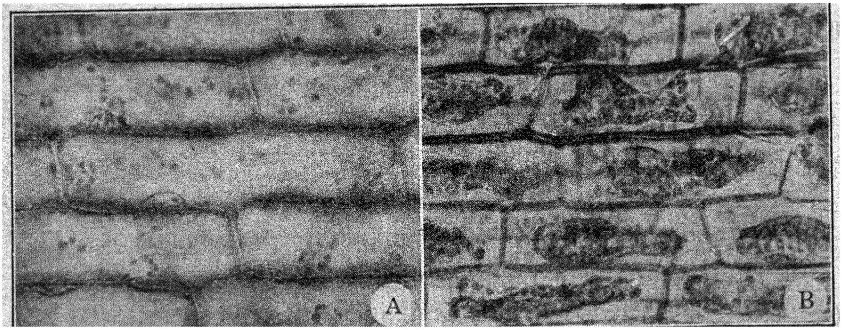


FIG. 40. Plasmolysis of cells (*Elodea*). *A*, normal cells; *B*, plasmolyzed in 10 per cent potassium nitrate. *Photomicrographs by H. L. Dean.*

there is more water to the solution of higher concentration where there is less water.

If a cell is bathed by a solution which has the same concentration as that of the sap inside the cell, there will be a state of osmotic equilibrium between the two solutions and therefore the osmotic pressure will remain unchanged.

Turgor. The cell usually contains materials in solution, and therefore there is an intake of water by osmosis; the resultant pressure stretches the cell wall, giving rise to a distension known as **turgor** (*turgere*—to swell). The cells in actively growing tissues are normally turgid, and only when the water supply is inadequate do they lose this turgor and become flaccid. In the condition of flaccidity the cell walls are not stretched, and this is the explanation of the appearance of a wilted plant (Fig. 41).

We shall see later that materials move into, through, and out of the plant by various combinations of the four physical processes: solution, diffusion, imbibition, and osmosis. We do not know all the details involved in the intake and conduction of materials, but within the limits of our present knowledge we think of these four processes as the most important factors involved.

FIG. 41. *A*, normally turgid erect marigold plant. *B*, the same plant when wilted by reason of the loss of water. *Photograph by W. E. Rumsey.*

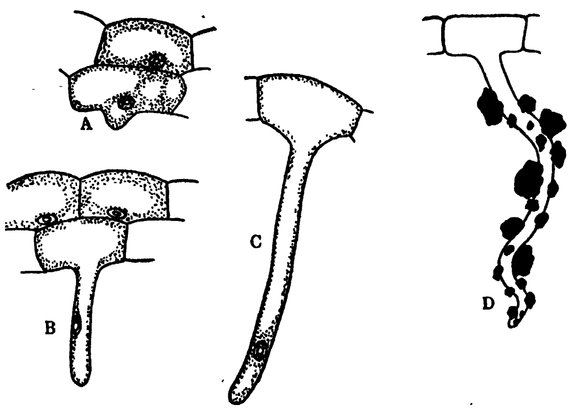


FIG. 42. *A–C*, three stages in the development of a root hair. *D*, soil particles clinging to a root hair. *Redrawn from Holman and Robbins, "Textbook of General Botany." (After Frank.)*

Intake of water and mineral salts. The raw materials taken in by the roots are water and various mineral salts in solution. The root hairs lying in close contact with the soil particles are bathed by the water films that adhere to these particles (Fig. 42). The wall of the root hair imbibes water and swells. Mineral salts of the soil are dissolved in the water film, which is a dilute solution whose concentration is lower than that of the cell sap within the root hairs. Consequently, in keeping with the general law of diffusion, water passes by osmosis into the root hair. In like manner the soil salts in solution diffuse into the root hairs. The molecules of the salts are not carried along by the water, but each moves according to its own diffusion rate. Once in the root hairs, the water molecules and the salt molecules pass by diffusion and osmosis from the epidermal cells into the cells of the cortical parenchyma. Thence, moving inward from cell to cell, the molecules traverse the cortical region and ultimately make their way into the xylem vessels. Here other factors, such as the cohesion of the water molecules, come into play to aid in the movement of the water and mineral salts upward through the xylem vessels into the leaves (Fig. 43).

For almost a century, plant physiologists, by growing plants in water cultures of known composition, have been studying the functions of the various chemical elements absorbed by roots. Thus we have learned something concerning the kinds and amounts of particular chemical elements needed for the development of a given crop, and the grower can render his soil more productive by adding the necessary mineral salts. A lively popular interest has developed in the growing of plants in water solutions of the proper mineral salts in place of soil. Beans, spinach, tomatoes, roses, sweetpeas, and many other plants can be grown in this way. Sometimes larger yields are obtained, but, on account of the expense involved, this method probably will never be employed in the commercial growing of plants. For the city dweller interested in plants, "chemical gardening" affords a genuine pleasure because he can grow his own sweetpeas and tomatoes in tanks in his small sun-parlor during any season of the year. Books describing in detail how to grow plants without soil are available, and the old expression "water culture" has been changed to "hydroponics," designated as a "new science."

PHOTOSYNTHESIS

The photosynthetic machine. The machines that carry on the photosynthetic process (*photos*—light; *synthesis*—putting together) are the chloroplasts, usually most abundant in the chlorenchyma of leaves. Chloroplasts contain the all-important green pigment chlorophyll, absolutely essential for photosynthesis. In addition to chlorophyll, the chloroplast contains other pigments—yellow pig-

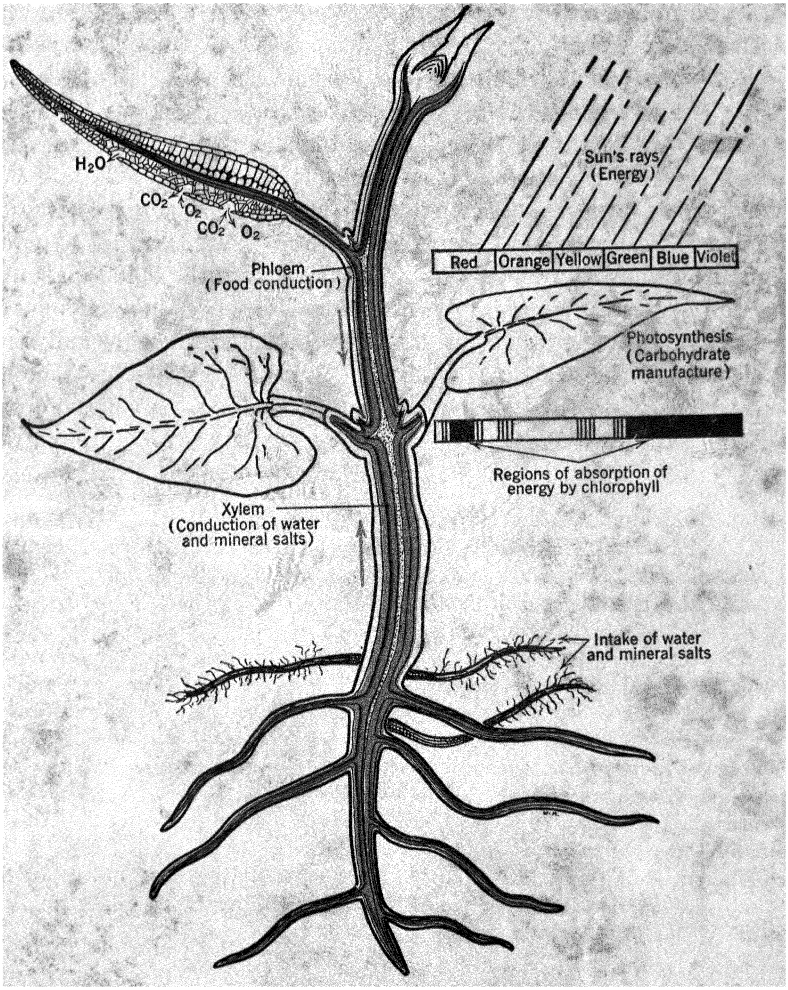


FIG. 43. Diagram showing the continuity of the vascular system and the various processes involved in photosynthesis. Xylem shown in red, phloem in blue.

ments called **xanthophylls** (*xanthos*—yellow; *phyllon*—leaf) and orange-colored pigments, the **carotinoids,** so called because of their abundance in carrots. The exact function of the yellow and orange pigments is not fully understood, but it is known that these pigments are more resistant than chlorophyll to the destructive influences of such factors as low temperature, drought, reduced light, injuries, and diseases. Consequently, in late summer and autumn, when some or all of these factors are likely to exert their greatest influence, the green pigment disintegrates first, leaving the orange and yellow pigments to be displayed in the gold and bronze of the forest during the period of autumnal coloration.

Specific differences in chloroplasts. The chloroplasts of different plants show a wide range of variation in their specific functional capacities. For example, in some plants the photosynthetic work is carried on at temperatures of 100° F.; in others this process goes on at freezing temperatures. Although there is such an evident adaptation to a considerable range of temperatures, it has been ascertained that in the temperate zones ordinary summer temperatures are most favorable for photosynthesis. Likewise there is a difference in the amount of light required for photosynthetic activity in the different species of plants. Some species can carry on photosynthesis best only in full sunlight; others find shaded situations more favorable. However, in general, diffuse light is more favorable than intense sunlight.

Raw materials. The raw materials used in photosynthesis are carbon dioxide and water. Carbon dioxide is a gaseous component of the atmosphere, occurring in the proportion of 3 or 4 parts to 10,000 parts of air. We have already seen how, by imbibition and osmosis, water passes from the surface of soil particles into the root hairs; how by diffusion and osmosis it passes from the epidermal cells into the cells of the cortex and on into the xylem, which conducts it upward through the roots and stems into the veins of the leaf and finally into the cells of the leaf chlorenchyma. We have also seen how the air enters through the stomas into the leaf. The walls of the chlorenchyma cells surrounding the intercellular spaces in the spongy tissue of the mesophyll are always moist, so that the carbon dioxide dissolves in this moisture and diffuses into the cells. The guard cells, through changes in turgor, can alter their shape and thus effect a closing or opening of the stoma. When the stomas are closed little or no carbon dioxide can enter, and under such conditions photosynthesis slows down or stops entirely.

Source of the energy. Sunlight is the energy that runs the photosynthetic machine. If radiant energy from the sun is passed through a prism, a miniature rainbow is produced in which we see the characteristic colors: red, orange, yellow, green, blue, indigo, and violet. These colors indicate that sunlight is a composite of energy waves differing in their physical characteristics.

The colors are accounted for by the fact that sunlight consists of energy waves of varying length, and the prism refracts or bends these waves to a lesser or greater degree according to their respective wavelengths, producing what is known as a **spectrum** (Fig. 43). Some of these energy waves affect the eye, and these we interpret as color—the visible portion of the spectrum. The so-called red rays, the longest waves that affect the eye, lie at one end of the visible spectrum, and at the other end are the violet rays, the shortest waves the eye can detect. Beyond the limits of the visible spectrum are still other energy waves. Beyond the red rays are the still longer invisible infra-red or heat waves, and beyond the violet rays are the shorter, invisible, ultraviolet and X-rays.

Absorption spectrum of chlorophyll. Now if a green leaf or a solution of chlorophyll is interposed between the light and a prism, dark bands appear in the spectrum showing that some of the light rays are absorbed by the chlorophyll. The absorption is seen to be greatest in the red, blue, and violet regions of the spectrum, with lesser absorption bands at other points (Fig. 43). Since it is known that there is a close relation between the kinds of light absorbed by the chlorophyll and the wavelengths that are effective in photosynthesis, a study of the absorption spectra shows what kinds (quality) of light are required in the manufacture of food. Under different environmental conditions these absorption bands are seen to occur at some different regions of the spectrum, and they also vary in their intensity. In strong sunlight absorption is greatest in the red end of the spectrum, whereas in diffuse light more absorption occurs at the blue end in the region of the shorter wavelengths. It has been shown that the red end of the spectrum is much more efficient photosynthetically than the blue end, owing to the fact that blue light represents less energy. Here, as always, the relation between work and energy is quite evident. This has been clearly and well stated as follows: "The photosynthetic work accomplished varies directly with the energy absorbed from the light regardless of the wavelength."

The process. In some way, the energy of light, in the presence of chlorophyll, breaks up the carbon dioxide molecule into carbon and oxygen and the water molecule into hydrogen and oxygen. In the chloroplast the carbon, hydrogen, and oxygen are combined to form a simple carbohydrate.

There are several different theories that attempt to explain the chemistry of photosynthesis, but to discuss any one of these fully would take us too far afield. Selecting one of the most widely accepted of these theories we find that this reaction may be represented by the following equation:

$$C + 2H + O \rightarrow \underset{\text{Formaldehyde}}{CH_2O}$$

The end product (CH_2O) is the simplest carbohydrate; it is known as **formaldehyde.** After this simple carbohydrate has been formed all the other carbohydrates known to occur in plants can be produced by a chemical process called **condensation.** For example, if six molecules of formaldehyde are combined by condensation a molecule of grape sugar or glucose will be formed:

$$6CH_2O \rightarrow \underset{\text{Glucose}}{C_6H_{12}O_6}$$

If a molecule of glucose is combined with a molecule of fructose, one molecule of cane sugar is formed with the resultant loss of one molecule of water:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6} \rightarrow \underset{\text{Cane sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O}$$

The more complex carbohydrates are formed by the condensation of a number of molecules of some simpler sugars with the elimination of one molecule of water for each molecule that enters into the combination. Thus the formation of starch may result from the condensation of n molecules of glucose:

$$\underset{\text{Glucose}}{n(C_6H_{12}O_6)} \rightarrow \underset{\text{Starch}}{n(C_6H_{10}O_5)_n} + \underset{\text{Water}}{n(H_2O)}$$

The ultimate product of photosynthesis is a carbohydrate, and it is quite generally believed that the first carbohydrate formed is formaldehyde, but it must be admitted that this view has not been accepted by all biologists. However, regardless of what the correct answer to this question may be, we do know beyond doubt that in a great majority of plants the first *visible* product formed is starch. Starch is a storage form of carbohydrate because it is insoluble and therefore cannot pass through a living membrane. If the soluble carbohydrates such as glucose, as they are being manufactured, were to accumulate in the chloroplast, the photosynthetic process would soon be greatly retarded; but by condensation, they are rapidly converted into starch. Thus they are removed from solution so that there is much less interference with the chemical processes going on in the chloroplast. In some few plants like the onion, no starch is formed, and in other plants a vegetable oil is formed instead of starch.

Efficiency of the photosynthetic machine. The efficiency of a machine is determined by comparing its output of energy in useful work with the total amount of energy consumed or transformed, i.e., the fuel used, such as coal or gas. If we compare the amount of carbo-

hydrate made by a leaf with the amount of solar energy it received, we can get some appreciation of the efficiency of the photosynthetic machine. Thus Brown showed that the leaf of a sunflower plant has an efficiency of only 0.5 per cent. However, Raber points out that, of the total light falling upon a leaf, approximately 30 per cent is reflected and transmitted, and only 70 per cent is absorbed by the leaf. Of this 70 per cent, only 3.5 per cent is absorbed by the chlorophyll apparatus and used in photosynthesis. Therefore it becomes necessary to multiply Brown's efficiency figure of 0.5 per cent by 100/3.5, which indicates that the real efficiency of the sunflower leaf is 15 per cent instead of 0.5 per cent.

Most of the light absorbed by the leaf is probably transformed into heat energy, and some of this radiating from the plant raises the temperature of the surrounding air. But most of this heat energy is used in vaporizing the water within the leaf, a process of great importance as we shall see later. It is believed by many workers that the light energy absorbed by the chlorophyll apparatus is transformed into electric energy. Since we are as yet unable to define exactly the various kinds of energy with respect to their inherent and fundamental nature it is perhaps sufficient for our present purpose simply to regard light as a form of kinetic energy that is in some way transformed into the potential energy of carbohydrates.

Importance of photosynthesis. We have seen that it is possible for green plants in the presence of sunlight to combine the elements of the inorganic compounds, carbon dioxide and water, into carbohydrates. Generally speaking, this process of photosynthesis is the most important of all life processes because it provides the food necessary for practically all living organisms. Since sunlight furnishes the energy for this process, it is obvious that the sun is the mainspring of life.

Translocation. Before starch can be used or removed from the chloroplast, it must be converted into a soluble carbohydrate. This is accomplished by **hydrolysis,** a very important process in all digestion. This reaction may be illustrated by the following equation:

$$\underset{\text{Starch}}{n(C_6H_{10}O_5)_n} + \underset{\text{Water}}{n(H_2O)} \rightarrow \underset{\text{Glucose}}{n(C_6H_{12}O_6)}$$

Glucose is soluble in water, and in solution it may be removed from the cell by osmosis and, with other substances, be carried by the sieve tubes of the phloem to all parts of the plant. If it goes to some remote storage region, such as a fleshy tap root or underground stem, it may be again condensed into disaccharides, starch, oils, or

other compounds insoluble in water, and stored in the cells. In grains, roots, and tubers these stored carbohydrates are of great importance either as food reserves for the plant producing them or as food for the development of new individuals. Likewise they form the largest part of the food of man.

Waste. In the process of photosynthesis, oxygen is given off as a byproduct. If we use a slightly different equation to indicate how the carbohydrate is formed, we have the following:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

An inspection of this equation shows that, for every molecule of glucose made, six molecules of carbon dioxide are required to furnish the necessary carbon, and six molecules of water to supply the hydrogen needed. But these amounts of water and carbon dioxide combined contain eighteen atoms of oxygen, which is twelve more than the number necessary to form a molecule of glucose. Consequently twelve atoms of oxygen are given off in this process as a byproduct or waste.

Organization. We have now seen how all the vegetative organs are coordinated in the business of food manufacture. The roots collect the water, and they may serve as storage regions for the finished product. The xylem vessels (vascular tissue) conduct the water up through the stem to the leaves. The stomas admit the air containing carbon dioxide. The chloroplasts are the machines that transform the energy of sunlight and bring about the combination of simple inorganic elements (C, H, and O) to form organic compounds—carbohydrates. The sieve tubes of the phloem (vascular tissue) carry the manufactured product to all parts of the plant. The organization is really not quite so simple as it is pictured here, but such a brief summary may serve to give a working knowledge of the green plant as a food-manufacturing establishment.

THE SYNTHESIS OF OTHER SUBSTANCES

Carbohydrates are the building stones for the formation of all other kinds of food substances. The synthesis of fats and proteins in both plants and animals starts with carbohydrate materials. Like starch, fats and oils are inactive storage substances—reservoirs of energy—and before they can be used or transported they must be converted by digestion into water-soluble substances. In the synthesis of fats, fatty acids and glycerol formed from carbohydrates are combined to form fats and oils (lipids) (Fig. 44). In plant cells at ordinary

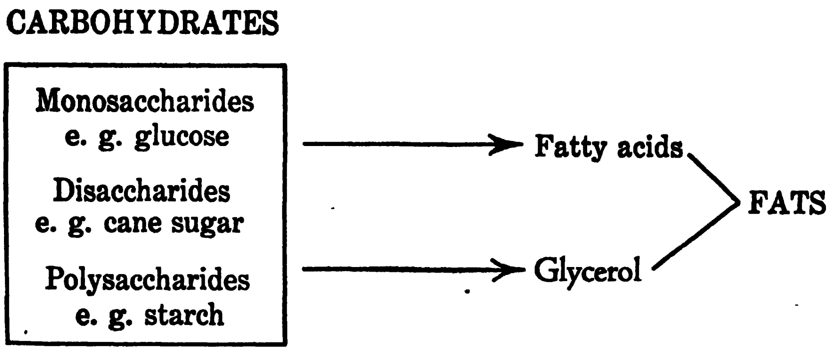


FIG. 44. Diagram of the synthesis of fats.

temperatures, fats may be present as both liquids and solids. In the liquid state fats are usually called oils.

The synthesis of proteins also begins with the carbohydrate molecule. However, proteins are far more complex compounds than either carbohydrates or fats. To get some appreciation of the size and complexity of the protein molecule we need only to glance at the empirical formulas of two common proteins:

Zein (a protein found in corn)	$C_{736}H_{1161}O_{208}N_{184}S_3$
Egg albumin	$C_{696}H_{1125}O_{220}N_{175}S_8$

In addition to carbon, hydrogen, and oxygen, all proteins contain the elements nitrogen and sulphur, and some of them also contain phosphorus, iron, and other elements. Although four-fifths of the air is nitrogen, the element in this gaseous state does not readily combine with other substances, and so it cannot generally be used by the green plant. Therefore the nitrogen, as well as the sulphur and phosphorus needed for protein synthesis, must be obtained from the soil. These elements occur in the soil as components of the mineral salts, the nitrogen being present chiefly in the form of nitrates (NO_3). These minerals when dissolved in water undergo physical and chemical changes, and the elements in solution pass into the roots as previously explained. The living protoplasm alone is responsible for the synthesis of proteins and fats. Because of their complex chemical composition and their peculiar physical properties, proteins are especially useful in the building of protoplasm.

There are several theories that attempt to explain how proteins are synthesized. Although the process is not yet fully understood, it is quite generally believed that the nitrates obtained from the soil are changed into ammonia (NH_3) within the plant. This ammonia

combines with certain acids derived from the carbohydrates to form **amino acids**—so called because each molecule contains the **amino group (NH_2)** and the **carboxyl group (COOH).** The simplest amino acid is glycine, and its molecular composition may be indicated thus:

$$
\begin{array}{c}
\mathrm{H} \\
| \\
\mathrm{H{-}C{-}NH_2} \\
| \\
\mathrm{O{=}C{-}O{-}H}
\end{array}
$$

See Fig. 45. Just as many glucose molecules may be joined to form a starch molecule, so numbers of amino acid molecules may join to

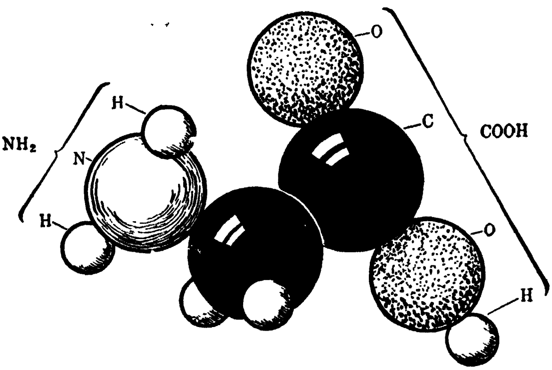


FIG. 45. Model of a molecule of an amino acid, glycine ($C_2H_5NO_2$). *Redrawn from Amberson and Smith, "Outline of Physiology." By permission of the artist, Norris Jones, and the Williams and Wilkins Co.*

form a molecule of protein. It is believed that some protein molecules are formed by the union of a hundred or more amino acid molecules (Fig. 46).

Proteins form more than 50 per cent of protoplasmic substance other than water. This role of proteins in the building of protoplasm indicates at once the importance of an adequate supply of nitrogen, sulphur, and phosphorus for the growing plant. Since approximately one-sixth of the protein is nitrogen, we can readily understand why a supply of nitrates in the soil is necessary. Soil with sufficient moisture contains the raw materials for the manufacture of both carbohydrates and fats, but nitrogen, sulphur, and phosphorus must be present to make possible the manufacture of proteins. When all other plant requirements are satisfied, it is the relative amounts of these three elements that determine the productive worth of agricultural soils.

To trace in detail the chemical synthesis of all the substances produced in plant and animal bodies would require more information than chemists have at present. However, it is well known that most interesting and mysterious "chemical laboratories" exist in the living cells of plants, where a great array of organic compounds is synthesized. Here are manufactured the anthocyanin pigments responsible for the red color of leaves and the red, blue, and purple colors of many of our flowers; the lignin of woody tissues; suberin, the important constituent of cork; resins, gums, and mucilages; latex,

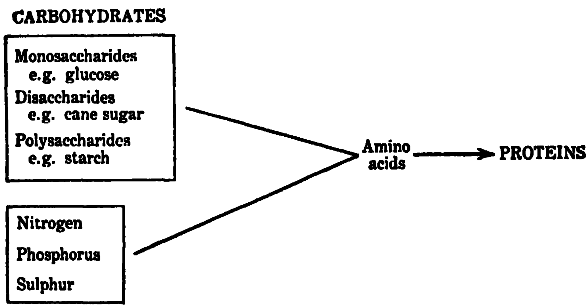


FIG. 46. Diagram of the synthesis of proteins.

the source of commercial rubber; alkaloids, used so largely in medicine; essential oils, used in medicines, extracts, and perfumes; tannins, used in tanning leather; and such extremely important substances as vitamins and enzymes.

THE FATE OF THE LEAF

Since we have noted the very important part played by the leaf in the synthesis of food materials, it is only natural that we should make some inquiry concerning the ultimate fate of the leaf. When leaves grow old, owing to the operation of internal factors or the effects of unfavorable environment, or both, the stored food materials are withdrawn from the blades through the petiole into the stem. Corky cells develop, forming across the basal end of the petiole a plate called the **abscission layer** (*ab*—from; *scindere*—to cut). The corky plate was given this name because it forms a line of weakness along which the petiole eventually breaks, causing the leaf to drop from the twig (Fig. 47). This abscission of leaves takes place in all plants that produce foliage but is more noticeable in deciduous trees where all the leaves fall at the end of the season in a comparatively short

period. Flowers, fruits, and even branches are detached in the same manner by the formation of an abscission layer. Although the physiological activities are arrested by the death of the leaf, the leaf continues to be useful by enriching and improving the soil for the growth of new foliage, new fruit, and new plants.

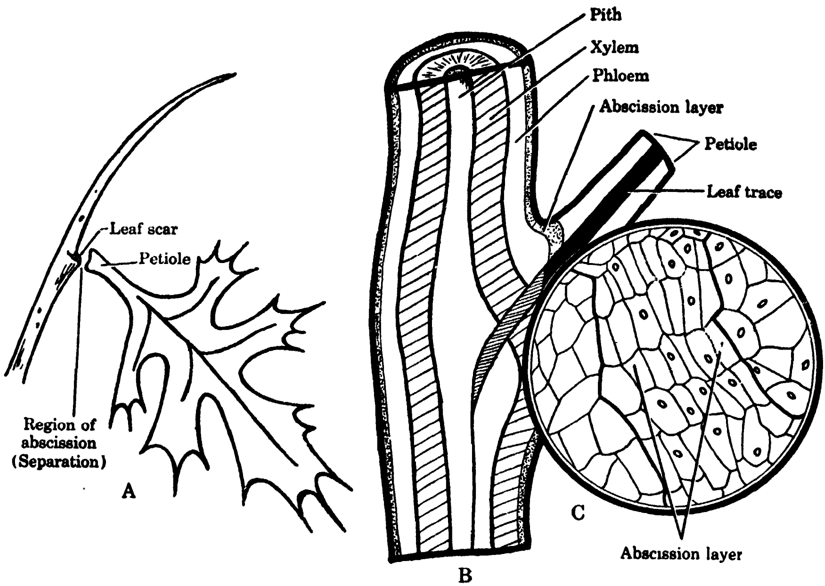


FIG. 47. Leaf abscission. *A,* abscission of an oak leaf. *B,* longitudinal section through the base of the petiole showing the formation of the abscission layer. *C,* a diagram showing the relation of the abscission layer to the other tissues.

Some deciduous trees like the oak, maple, and beech may fail to shed their leaves in autumn. The dead leaves remain on the trees through the winter and in the following spring are detached by the formation of a belated abscission layer. Evergreen or non-deciduous trees, such as hemlock, pine, and spruce, do not shed all their leaves at any one time, so that a crown of green foliage is present throughout the year. However, some leaves are being shed during most of the year, and therefore the term non-deciduous when applied to these trees is a misnomer.

IMPORTANCE OF PLANTS TO MAN

We have already noted the fundamental importance of photosynthesis as the manufacturing process that provides the food necessary for all living organisms. We have also learned that a large number of substances of various kinds are synthesized in the cells of plants. Through the experience of many generations,

man has learned to use plants as a source of needed materials and also luxuries of many kinds.

Economic importance of leaves. Food materials and vitamins necessary for the maintenance of life and well-being in both man and his domestic animals are manufactured by leaves. Grasses are widely distributed throughout the world, and the foliage of these and other plants furnishes a very large part of the food consumed by horses, cattle, sheep, and other animals. Among plants whose leaves form a part of man's diet are lettuce, endive, chard, spinach, celery, cabbage, kale, broccoli, Brussels sprouts, collards, artichoke, mustard, water cress, and rhubarb. Man's cigarettes, cigars, snuff, and pipe and chewing tobacco represent the production by the tobacco plant of tons of leaves annually. The tea we drink is made by steeping the leaves of the tea plant. Thyme, sage, peppermint, and pennyroyal may grow in our gardens, but the tea of commerce is produced by an oriental plant grown extensively in both China and Japan. Leaves of various plants also provide large quantities of both dyes and drugs.

Economic importance of stems. Stems are of greatest value to man in supplying wood for building and manufacturing. An almost inconceivably large number of items are made of wood itself, and wood derivatives are used today to make an ever-increasing list of widely different things. Among such derivatives are acetone, creosote, turpentine, dyes, tannins, and gums. Wood also supplies the cellulose for making paper, photographic film, celluloid, cellophane, shatter-proof glass, rayon, and plastics of many kinds. Stems furnish many other valuable products such as cork and fibers previously mentioned, rubber, medicinal substances, tannins, dyes, perfumes, chicle for chewing gum, turpentine, gums, lacquer, and spices. Stems and stem products are also utilized as food for both man and beast.

Economic importance of roots. As storage organs, roots accumulate much material of value to man. The more common plants whose roots are used as food are sweet potatoes, yams, radishes, rutabagas, turnips, carrots, beets, parsnips, and salsify. The roots of many plants contain storage substances that furnish valuable drugs. Such medicinal plants are mayapple, ginseng, goldenseal, gentian, rhubarb, aconite, asafetida, valerian, marshmallow, and licorice. Spices are obtained from the roots of such plants as horseradish, turmeric, and sassafras. Roots also furnish dyes like "turkey red" obtained from the roots of madder.

The importance of roots as "soil binders" cannot be overemphasized. Wherever plants with fibrous root systems grow close together, the meshwork of rootlets tends to bind the soil particles together and hold them in place. This soil-holding power of roots effectively checks the erosive action of both wind and water, and consequently plants are now recognized as man's most helpful allies in the work of soil conservation.

SUMMARY

Having studied the structure and function of each vegetative organ of the plant we are now prepared to entertain a new and somewhat different idea of the organism as a whole. We have seen how the roots are adjusted to the soil environment and how they procure some

of the raw materials used by the plant; how the leaves are adjusted to an air environment and how they procure carbon dioxide from the air and use it in the manufacture of food. We have seen that the stem is the medium of communication between the roots and the leaves and that, through its branching, provision is made for a large display of foliage. The xylem extending from the roots through the stem into the leaves conducts the water and mineral salts into the leaves, and the phloem conducts the food from the leaves into the stem, thence on through the stem to the root. The green chloroplasts wherever found, but especially in the leaf, through the agency of sunlight, convert inorganic materials (carbon dioxide and water) into organic materials (carbohydrates) with the release of oxygen. These carbohydrates constitute the food that supplies the energy and building material necessary for the life, growth, and reproduction of the plant. They also constitute either directly or indirectly the food supply of all animal life. In addition to carbohydrates, many other substances are synthesized in the cells of plants. Man has learned how to use plants to supply his many needs, and therefore leaves, stems, and roots have very great economic importance.

Thus we have learned that the organs of the plant have become adapted to the performance of certain specific functions and that all these functions are correlated in the activities of the organism as a whole. These activities are the manifestation of that mysterious something we call life. Having learned how the plant manufactures food, we shall next attempt to find out how this food is used by both plants and animals.

CHAPTER IV

METABOLISM (*Continued*). HOW CAN FOOD BE DIGESTED AND ABSORBED?

We have already noted the importance of solution as a physical process involved in the translocation of material and the role of water as a common solvent. We shall now attempt to find out how food substances are dissolved and to learn something about the high degree of specialization of organic structure associated with this phase of biological activity.

DIGESTION

Foods that are insoluble cannot be utilized by living organisms until they are converted into soluble substances. If soluble foods cannot diffuse readily through protoplasmic membranes, their movement from one place to another will be greatly retarded or entirely prohibited. They will be ready for use, if at all, chiefly in the cell where they chance to be. The transformation of food from an insoluble to a soluble form, and from a non-diffusible to a diffusible condition, is known as **digestion.** The processes of digestion are essentially the same in plants and in animals; "they are wrought by the same sorts of agents, affect the same sorts of substances, and result in the same sorts of products." However, plants have no highly specialized organs of digestion comparable to those found in animals.

Hydrolysis. The changes effected by digestion involve the cleavage of compounds into two or more simple substances accompanied by the taking up of water. As we have previously pointed out, such cleavage is called **hydrolysis.** The chemical changes in foods consist of hydrolyses by which the foods are converted into simpler, soluble substances. When we were studying the synthesis of foods we observed that fats were formed by the combination of glycerol and fatty acids. In digestion this process is reversed; in hydrolysis water is taken up and the fat is hydrolyzed to glycerol and fatty acids. In the same way complex carbohydrates are split into sugars, and proteins into amino acids.

ENZYMES

Catalysis and Catalysts. The chemical changes involved in digestion represent only a few of the many reactions that take place in living cells. These reactions are governed by the same laws that operate in the control of chemical reactions in general. For example, temperature, concentration, and the presence of materials other than the reacting substances all influence the rate and nature of these reactions. If potassium chlorate is heated in a test tube, oxygen is liberated, but the reaction proceeds very slowly. However, if, before heating, a small quantity of manganese dioxide is added to the potassium chlorate, the velocity of the decomposition will be greatly accelerated. Any such substance that tends to speed up or retard reactions by which compounds are broken down or synthesized, without itself being affected, is known as a **catalyst** (*kata*—down; *lysis*—loosening), and the effect it has on the reaction is called **catalysis.** In the decomposition of potassium chlorate, manganese dioxide acts as a catalyst, and it remains unchanged at the end of the reaction. Under the influence of catalysts, reactions which ordinarily take place so slowly that they cannot be detected may be speeded up until they are easily recognized. On the other hand, exceedingly rapid reactions may be retarded until they seem to cease altogether. We do not understand fully how catalysts operate to affect the rate of chemical reactions. Doubtless the activity of these agents is far more common and of much greater significance than has yet been realized. It is generally believed that catalysts are unable to initiate reactions. The generally accepted definition of a catalyst is: A substance which alters the velocity of a chemical reaction without undergoing any apparent physical or chemical change in itself and without becoming a part of the product formed.

How enzymes are named and classified. Included in the list of catalytic agents known to the chemist are certain substances produced in living cells and called **enzymes** (*en*—in; *zyme*—yeast). An enzyme has been defined as an organic catalyst, elaborated by an animal or plant cell, whose activity is entirely independent of any of the life processes of such a cell. Among the processes involving enzyme action, one of the first to be studied was the fermentation of yeast. At that early time, catalyzers, such as the enzyme of yeast, were known to act only in connection with the living cell, and consequently they were called "organized ferments." However, when Büchner in 1897 demonstrated that an active substance was present

in the liquid extracted from yeast cells after they were ground up and destroyed, the distinction between organized and unorganized ferments disappeared.

A prominent biochemist lists forty major groups of enzymes. For a full understanding of life, not only is it necessary to know the chemical constituents of protoplasm and their organization, but we must also have complete knowledge of the enzymes and the part they play in chemical reactions. It is now believed that these agents are involved in all chemical reactions that take place in living protoplasm. Here we are interested only in those enzymes that have part in digestion, for they are the active agents in all the chemical processes of this important function. Enzymes are named and classified according to the specific reaction with which they are concerned, or the nature of the substance (substrate) acted upon. The four most important general classes of digestive enzymes are:

Lipolytic enzymes, concerned with hydrolysis of fats (lipids).
Proteolytic enzymes, concerned with the hydrolysis of proteins.
Amylolytic enzymes, concerned with the hydrolysis of starch.
Sugar-splitting enzymes, concerned with the hydrolysis of sugars.

In naming the enzyme with reference to the particular substrate on which it acts, the termination *ase* is affixed to some part of the name of the substrate. Thus lipase is the name given to any enzyme involved in the hydrolysis of lipids; amylase (*amylon*—starch) digests starch; and protease digests proteins.

Nature and specificity of enzymes. Although the chemical nature of enzymes has not been determined with any degree of accuracy, it is generally believed that all are colloids resembling proteins in composition. In general, these substances are most active within a rather narrow range of temperature (30–45° C.), and most of them are entirely destroyed when the temperature rises to 60–75° C. They are inactivated by lower temperatures but again become active when the temperature is increased. A very small amount of an enzyme can effect changes in an almost unlimited quantity of substrate, because the enzyme is not consumed but may be used over and over again like any other catalyst.

Enzymes are specific in their action; that is, some one enzyme is responsible for a particular chemical change in a given substance or group of closely related substances. Thus sucrase, a plant enzyme, acts only on sucrose, and ptyalin, an animal enzyme, acts only on starch. This evident relation between enzyme and substrate is known

as "specificity of enzyme action." At the present time we have no satisfactory explanation of this relationship.

Reversibility of enzyme action. The reaction of some enzymes is known to be reversible; that is, under certain conditions an enzyme will accelerate the breaking up of a given substance into simpler compounds, whereas under another set of conditions the same enzyme may accelerate the combination of simpler substances into a more complex compound. Thus fats that are hydrolyzed by the action of lipase have been synthesized from glycerol and fatty acids by the agency of this same enzyme. Likewise the sugar, maltose, has been synthesized from glucose by the enzyme maltase. Apparently it is the nature of the conditions under which the enzyme is working that determines the direction of the reaction, and therefore the same enzyme may accelerate either the hydrolytic or the synthetic reaction. We know much less about the constructive role of enzymes than about their disintegrating activity, but it seems very probable that we shall ultimately discover that enzymes have a part to play in synthetic processes that is fully as important as their role in digestion.

DIGESTION IN PLANTS

Digestion of starch. It has already been indicated that there is no digestive tract in plants, but apparently digestive enzymes are present in the cells of all living plant tissue. In the more complex plants, with few exceptions, the processes of digestion are carried on in the living cells—**intracellular digestion.** However, in the simplest plants, digestion may take place outside the cells through the agency of excreted enzymes; this process is known as **extracellular digestion.** We have already observed how starch is formed in the leaves of plants. Since starch is insoluble in water, before it can be used or transported to other parts of the plant it must be converted into soluble and diffusible substances. The enzyme **diastase,** found in practically all parts of the plant but especially abundant in leaves and storage organs, is responsible for the transformation of starch (Fig. 48). In fact, it is probable that what is called diastase is really two enzymes: **amylase,** which converts starch into dextrin; and **dextrinase,** which transforms dextrin into maltose. The maltose is then changed by **maltase** into glucose, a simple soluble sugar that can enter the cell and be utilized by the protoplasm either to furnish energy or to serve as building material. If such a soluble sugar is carried to the roots to be stored there, it must be resynthesized into starch, and before the starch can be used it must be digested again.

Digestion of fats and proteins. Fats and proteins must also be digested before they can be used or transported from one part of the plant to another. Fats (lipids) are acted upon by lipases and converted into glycerol and fatty acids. Proteins are acted upon by several enzymes of the group known as proteases, being broken up into peptones and finally into amino acids, which are freely soluble and diffusible. Subsequently we shall see how these same digestive processes are performed through the agency of similar enzymes in the much more complicated digestive system of the animal body.

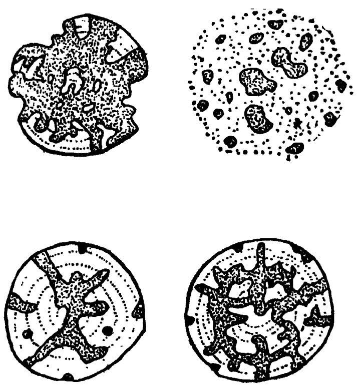


FIG. 48. Corroded, partly digested starch grains. *From Holman and Robbins, "Textbook of General Botany." By permission of John Wiley & Sons.*

Carnivorous plants. Some interesting and unusual plants are capable of performing both intracellular and extracellular digestion. In this group are the pitcher plant, bladderwort, sundew, Venus' flytrap, and others (Fig. 49)—plants that grow in bogs or poorly drained soils having a very low nitrogen content. As nitrogen is an essential element in the building of proteins and protoplasm, these plants have developed some interesting leaf modifications that enable them to secure nitrogen from another source. In the pitcher plant and bladderwort (Figs. 49 and 50) the leaf blades have become modified to form cups, pitchers, or bladders that may contain water. Visiting insects of various kinds are drowned in this liquid and attacked by proteolytic enzymes excreted by the cells of the leaf. These enzymes digest the proteins of the insect bodies, converting them into soluble peptones and probably amino acids, which then diffuse into the cells of the leaf, supplying the plant with the indispensable nitrogen. Because they consume animal bodies (insects) these plants are called **carnivorous** (*caro*—flesh; *vorare*—to devour) or **insectivorous plants.** The leaves of the sundew (Fig. 49) are covered with long glandular hairs that secrete a viscid substance making the leaf surface sticky like flypaper. An insect alighting upon the leaf is unable to escape and is gradually digested by enzymes secreted by the leaf. The same thing occurs in Venus' flytrap (Fig. 50), only here the mechanism is different. The two halves of the blade can fold together as if they were hinged along the midrib. When a fly or other insect alights upon the upper surface of the leaf the blade folds up, effectively trapping the

insect between the contiguous surfaces, where it is slowly digested. In all these plants digestion is extracellular. Although other sub-

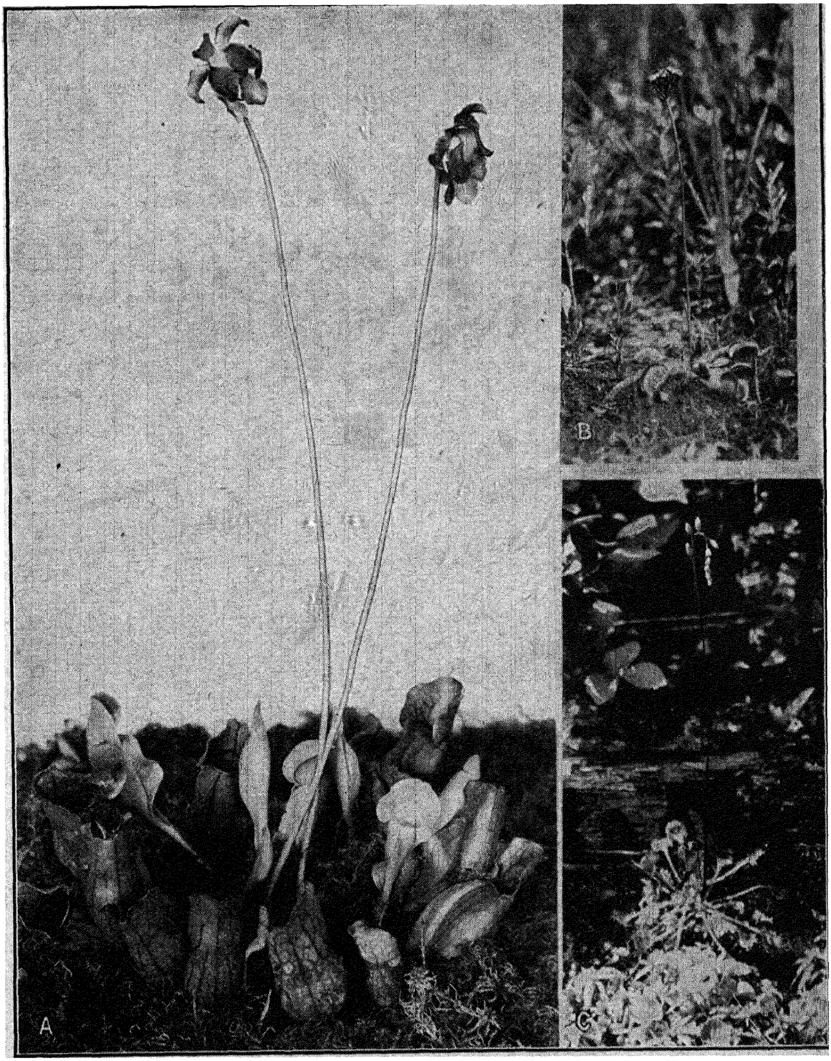


FIG. 49. Carnivorous plants. *A*, pitcher plant (*Sarracenia*). *B*, Venus' flytrap (*Dionaea*). *C*, sundew (*Drosera*). *Photographs A and C by W. E. Rumsey; B by B. W. Wells.*

stances may also be absorbed in the process, the nitrogen-containing substances are in all probability the most important nutrients obtained in this way.

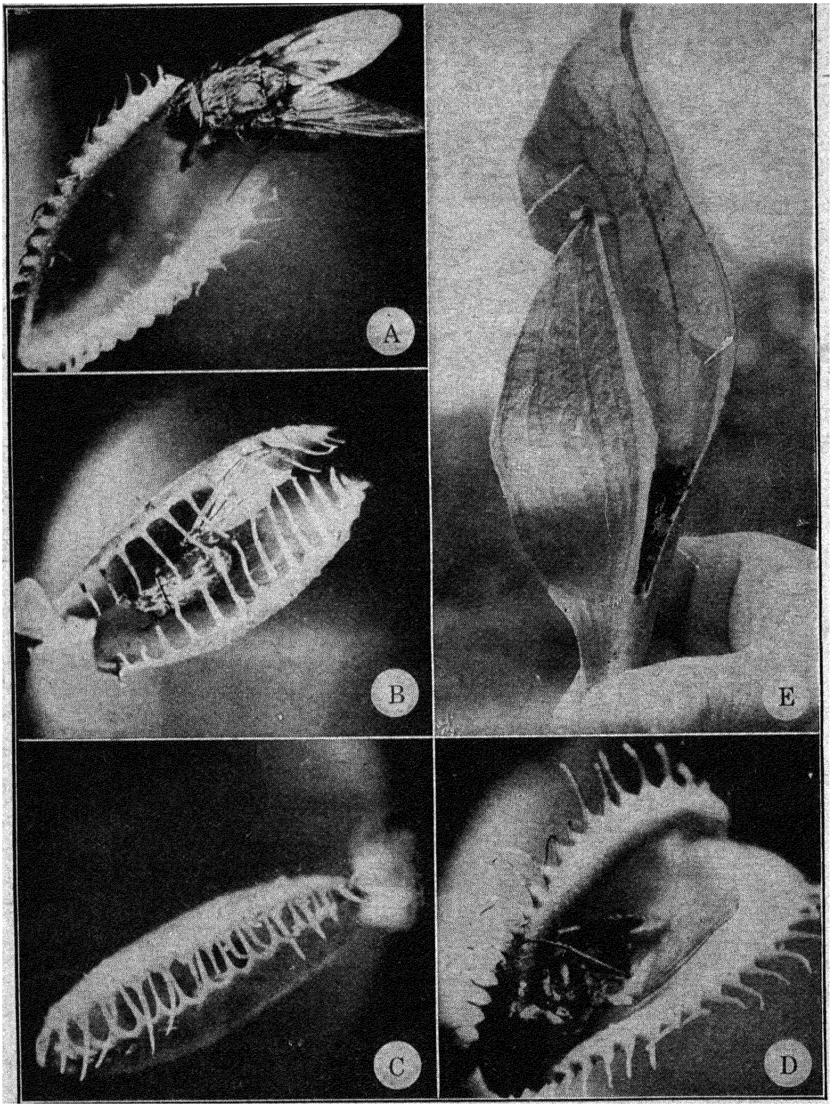


FIG. 50. Leaf of Venus' flytrap and leaf of pitcher plant (*E*). *A,* fly is lighting on the leaf; *B,* leaf closing to trap the fly; *C,* leaf tightly closed covering the fly; *D,* the leaf opened, showing the indigestible remains of the fly. *E,* leaf of pitcher plant with section removed showing accumulation of indigestible insect remains. *A–D by permission of General Biological Supply House; E, photograph furnished by Dr. John Trainer.*

DIGESTION IN ANIMALS

We have already seen that, by the process of photosynthesis, plants are able to manufacture or synthesize their carbohydrates from the inorganic materials carbon dioxide and water. These carbohydrates form the basis for further synthesis of fats and proteins. Animals, on the other hand, depend entirely upon plants for their basic food supply. In spite of the fact that plants manufacture their own foods, nevertheless, for purposes of transportation, assimilation, and resynthesis into new materials necessary for the life of the plant, plant foods must be broken down into simpler substances by a process called digestion. The same is true of animals. Their food—carbohydrates, fats, and proteins—whether animal or vegetable material, must be broken down, absorbed, transported to various parts of the animal, and resynthesized or assimilated into other compounds making up the animal structure.

The Animal Food Machine

In all the higher animals the process of digestion takes place in the **alimentary canal** (*alimentum*—nourishment) which, with its various regions and associated digestive organs, is practically the same in all backboned animals (vertebrates). In some of the higher nonbackboned forms (invertebrates), such as the crayfish and earthworm, the alimentary canal has somewhat the same general regions. We shall now study the alimentary canal and associated digestive organs of man, a backboned animal; later we shall compare the structures and functions of the digestive organs of various animals.

In the alimentary canal the food is acted upon by secretions derived not only from the canal itself but also from the associated glands or organs. The process of digestion is also facilitated by mechanical movements of the wall of the canal.

The alimentary tract. The body of all higher animals is essentially a double-walled tube. The outer tube is the outer body wall with which we are familiar, and running through this is an inner tube, the alimentary canal. Between the alimentary canal and the body wall is a space called the **coelom** or **body cavity,** in which are found most of the digestive organs of the body. These organs and the alimentary canal are anchored to the outer body wall and suspended by sheets of tough tissue called **mesenteries.**

The entrance to the alimentary canal is the **mouth,** which opens into the **buccal cavity** (*bucca*—cheek), bounded by the **upper** and **lower jaws.** Normally in both the upper and lower jaws of man there are **teeth,** differentiated into **incisors, canines, bicuspids,** and **molars** (Fig. 51). In many species of vertebrate animals, all the teeth have the same pattern. A tooth consists of the **crown,** the portion exposed above the gum, and the **root** embedded in the jaw bone (Fig. 52). The crown is covered with resistant **enamel.** Under the enamel is the **dentine,** containing the central **pulp cavity,** in which are blood vessels, nerves, and connective tissue (Fig. 52). The buccal cavity merges imperceptibly into the **pharynx** or throat, from which

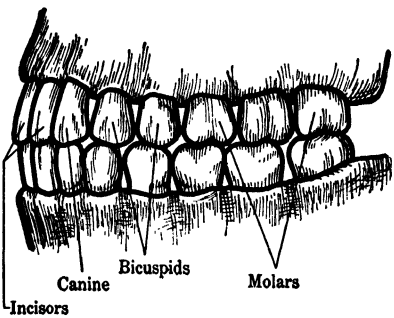


FIG. 51. Human teeth

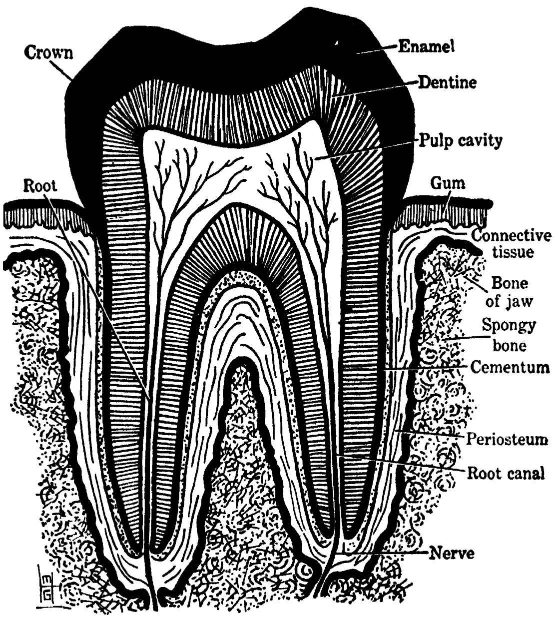


FIG. 52. Longitudinal section of tooth, showing structure.

extends a more or less elongated tube, the **esophagus,** leading into an enlarged sac-like **stomach.** From the stomach the alimentary canal continues as the much-coiled **small intestine,** which leads into the

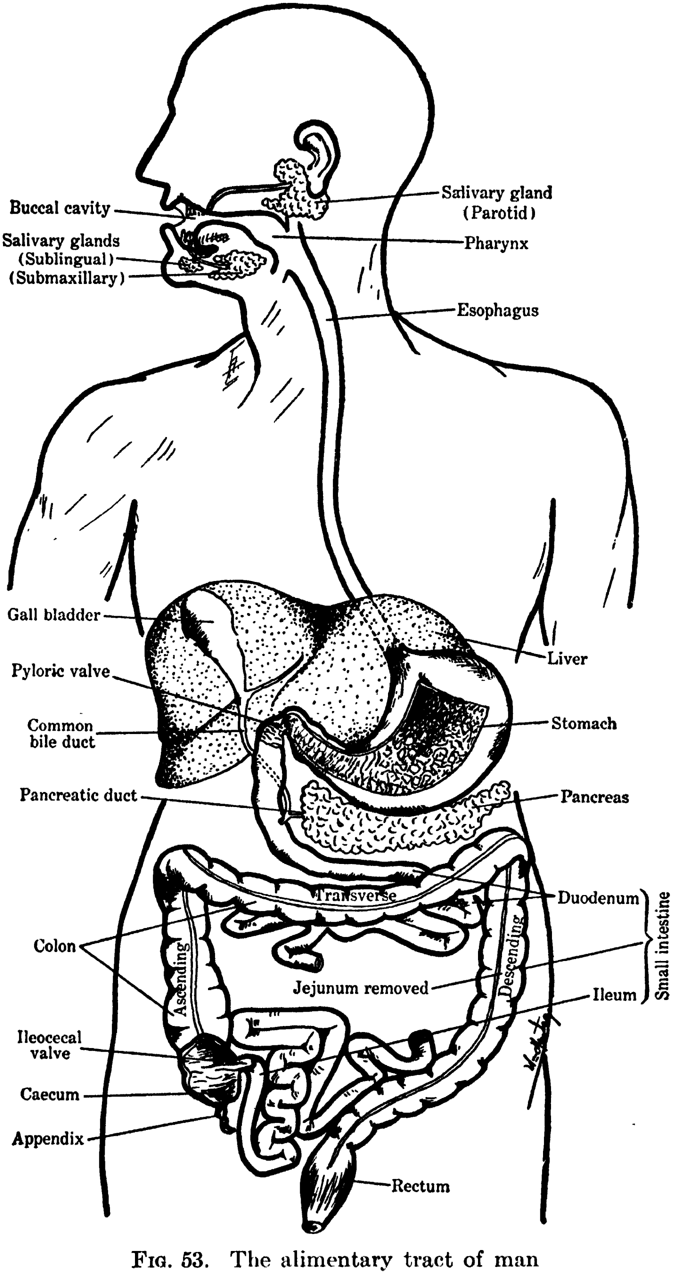


FIG. 53. The alimentary tract of man

large intestine or **colon,** the lowest region of which, the **rectum,** opens to the outside through the **anus.** The opening of the stomach into the small intestine is controlled by the **pyloric valve** (*pyloros*—gatekeeper), which is a ring of specialized muscle (Figs. 53 and 54). The entrance of the small intestine into the colon is regulated by the **ileocaecal valve,** similar in structure to the pyloric valve.

At the junction of the small intestine with the large intestine there is a small blind sac called the **caecum** (*caecus*—blind). Extending from the end of the caecum, in man, is a small fingerlike, hollow out-

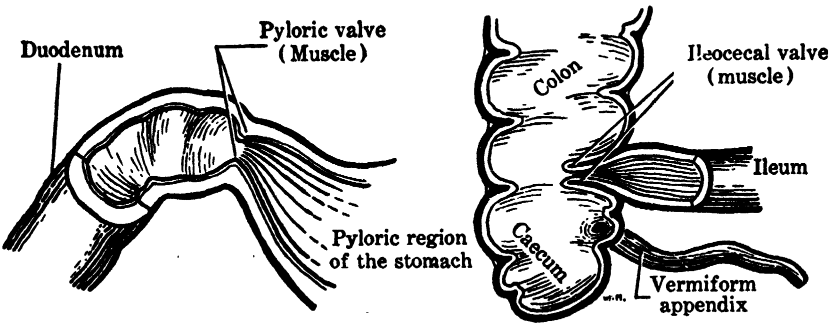


FIG. 54. Pyloric and ileocecal valves.

growth, the **vermiform appendix** (Fig. 54). An infection of this appendage together with the resultant inflammation is **appendicitis.**

Starting anteriorally, the small intestine is divided into three general regions: the **duodenum,** the **jejunum,** and the **ileum.** The colon likewise has three main regions named from their relative positions: the **ascending, transverse,** and **descending colon** (Fig. 53).

Tissues. We have seen that, in the plant kingdom, a group of similar cells coordinated in the performance of some definite function is known as a tissue. Some examples of tissues are zylem, phloem, and cambium. We have seen that these tissues are organized into certain structural units which have definite functions to perform. These units, such as the leaf, root, and stem, were called **organs.** Likewise in the animal kingdom there are groups of similar cells called tissues which may be organized into structural and functional units called organs.

There are four principal groups of animal tissues: **epithelium; connective** or **supporting; contractile** or **muscular;** and **nervous** (Fig. 55).

EPITHELIUM (*epi*—upon; *thele*—nipple). Epithelial tissue covers or lines parts of the body. It may function to protect surfaces, to

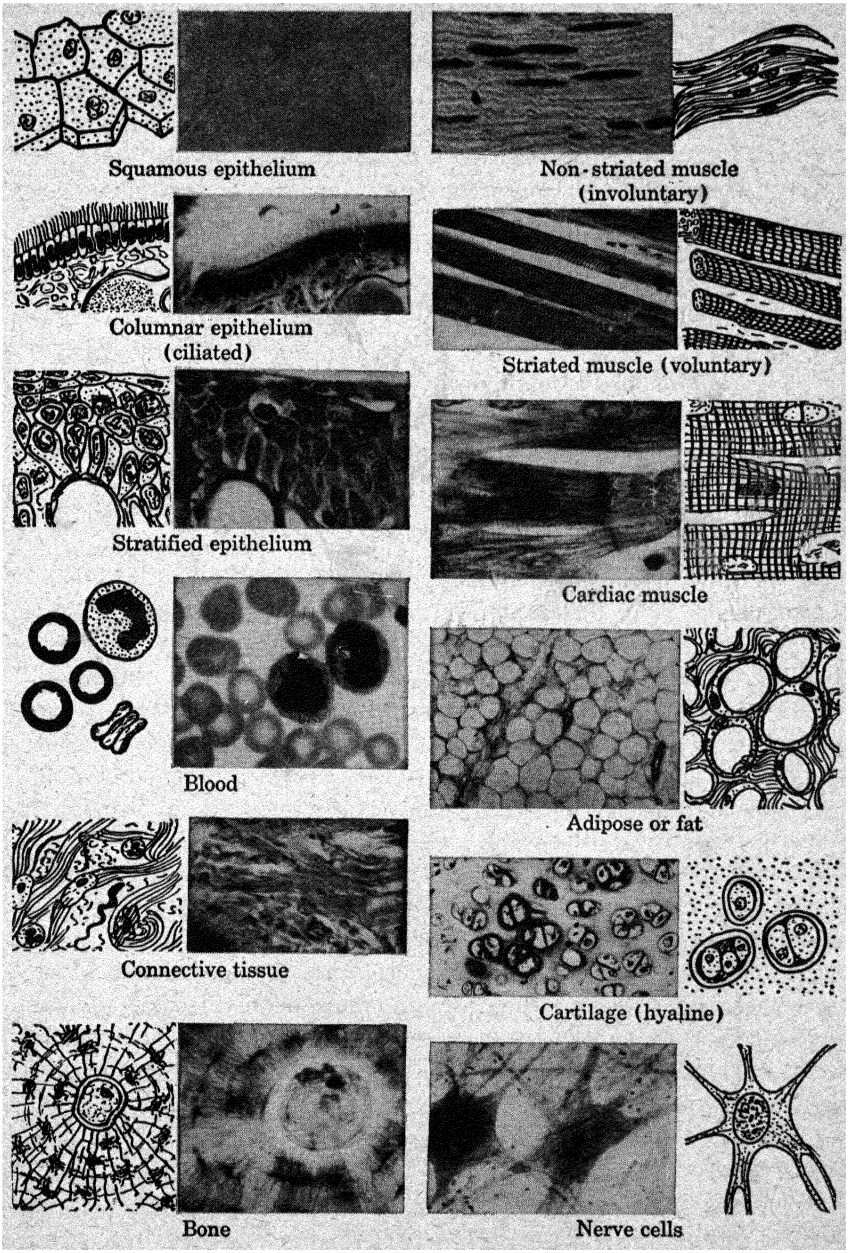


FIG. 55. Types of animal tissues. *Photomicrographs by permission of General Biological Supply House.*

form the secreting parts of glands, or to aid in absorption. Some epithelial tissues are sensory and others are reproductive in function. Various types of epithelial tissue are recognized and classified according to the structure, shape, and arrangement of the cells (Fig. 55).

Squamous epithelium is made up of flattened, tile-like cells, as may be seen in the covering of the intestine.

Cuboidal epithelium, made up of cells which are of equal dimensions, lines the ducts of glands.

Columnar epithelium is composed of cells whose height exceeds the width. An example is the mucosa or digestive epithelium of the intestine.

Ciliated epithelium is made up of cells which may have fine hair-like structures called **cilia** on the free surface. Columnar cells bearing cilia form **ciliated columnar epithelium,** as the lining of the trachea or windpipe.

Stratified epithelium occurs when a surface is covered with an epithelium several cell layers thick. The outer cells, which are hardened (cornified), are constantly worn away to be replaced by others from a deeper layer. Stratified epithelium is found on surfaces constantly exposed to abrasive action, such as the skin of the body and the inside of the cheek.

CONNECTIVE OR SUPPORTING TISSUE. Supporting tissues serve somewhat as a framework to support and bind together various parts of the animal body. Sometimes they are used for food storage (fat cells) and sometimes for transportation (blood and lymph). Sometimes, as in cartilage and bone, the support afforded by these tissues does not depend upon the cells proper but upon intercellular materials formed on the surfaces of and between the cells. The commoner types (Fig. 55) of supporting tissues are:

Connective tissue proper, of various types, is used to bind other tissues together to form structures and organs. This tissue is pliable and often occurs in sheets called mesenteries, or forms cords or **ligaments.** Toughness of meat is due to an abundance of connective tissue.

Cartilage is somewhat less elastic and of firmer consistency than connective tissue. It is much less rigid but more elastic than bone. The support of the outer ear is cartilage, as is also the voice box or larynx, familiarly known as "Adam's apple."

Bone is the most rigid, non-elastic supporting tissue. The bulk of the bone is made up of the secretion of the bone-forming cells **(osteoblasts).** The solid portion is intercellular and is laid down in sheets called **lamellae** (*lamella*—small plate). The bone is covered with a

membrane called the **periosteum** (*peri*—around; *osteum*—bone) which can form new bone after an injury.

Adipose or *fat tissue* is made up of cells which are almost entirely filled with oily fat. The nucleus and cytoplasm are crowded to the side of the cell, which causes it to resemble a signet ring.

Blood and *lymph* are commonly regarded as connective tissue having a liquid intercellular matrix which is not produced by the blood cells found floating in the fluid.

MUSCULAR OR CONTRACTILE TISSUE. Muscle tissue is made up of elongated cells in the form of **fibers** specialized for contractility (Fig. 55). This power of contraction is due to a special substance organized into **myofibrils** (*mys*—muscle; *fibrilla*—a small fiber) which are found inside the cell and, grouped together, form a muscle fiber surrounded by an elastic membrane, the **sarcolemma** (*sarx*—flesh; *lemma*—skin). These fibers in turn are bound together by connective tissues to form the muscle, which is surrounded by a tough sheath of connective tissue. This tissue may continue as a **tendon** by which the muscle is attached to the bone. There are three types of muscle.

Striated or *voluntary muscle* is distinguished by the presence of alternating light and dark stripes across the fibers. Striated muscle is usually found where rapid motion is required. Most muscles under control of the will are of this type, but there are some exceptions which will be pointed out later. The huge muscles that move the limbs are striated muscles.

Non-striated or *smooth muscle* is a primitive type of muscle in which there are no cross striations. Smooth muscle, often called **involuntary muscle,** is found most often in the internal organs, such as those of the digestive tract, whose movements are automatic and not under control of the will (Fig. 55). Smooth muscle is quite common in the lower animals.

Cardiac muscle is a special kind of muscle found in the heart of backboned animals. Although this muscle is involuntary in function, it has striations characteristic of voluntary muscles. The fibers branch and unite with fibers from adjoining cells. The cells of this tissue, not separated by cross walls, form a mass of protoplasm containing many nuclei. Such a tissue is a **syncytium.**

NERVOUS TISSUE. Nervous tissue is made up of specialized cells called **neurons.** The function of this tissue is to receive and transmit impulses from one part of an animal to another. Neurons may be grouped into masses called **ganglia,** from which may extend **nerve fibers** grouped within a common sheath to form a **nerve** (Fig. 55).

Glands. Single cells or groups of cells which are specialized for the synthesis and secretion of particular substances are known as **glands.** The secreting tissue of a gland is an epithelium. There are various types of glands (Fig. 56).

UNICELLULAR GLANDS occur as scattered cells concerned in secretion. Such cells or glands are found in the digestive epithelium of

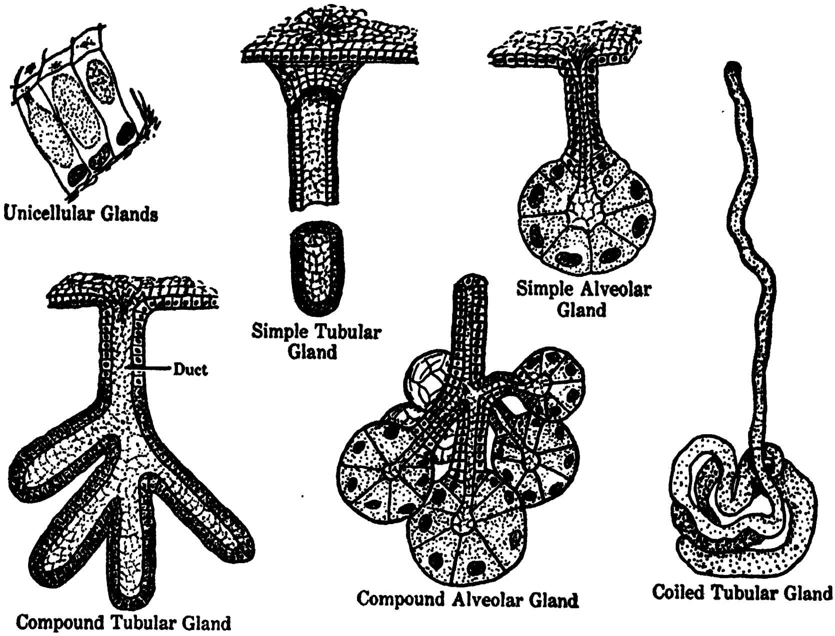


FIG. 56. Types of glands.

the intestine and in the outer epithelium of the earthworm. Sometimes these gland cells may enlarge and push down from the epithelial layer into the underlying connective tissue.

SIMPLE TUBULAR GLANDS occur when localized regions of the epithelial layer become infolded or invaginated, forming tubular structures lined with secretory epithelial cells. The cavity of the gland is called the **lumen,** and the tube leading from the gland proper to the place where it empties on the surface is known as the **neck** or **duct.** A good example of a simple tubular gland which is coiled in its deepest portion is the sweat gland of the skin (Fig. 56).

SIMPLE ALVEOLAR GLANDS may have the same origin as the simple tubular glands, but they are flask shaped or bulblike. Glands of this type are found in the frog's skin (Fig. 56).

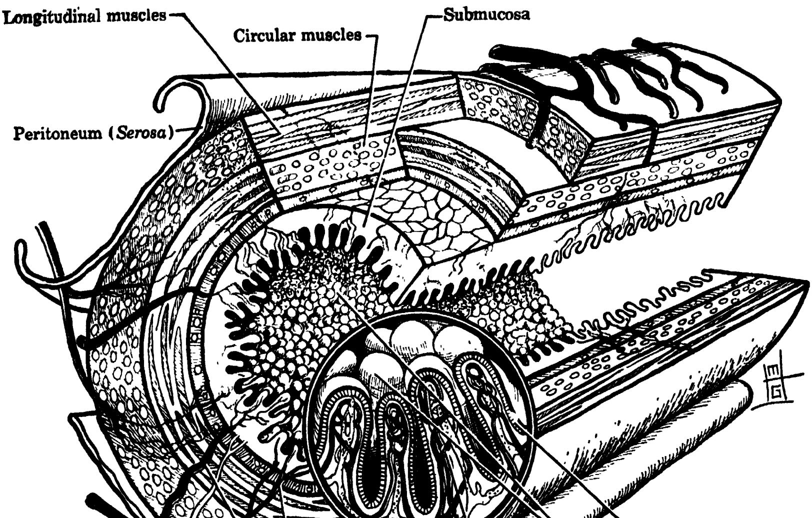


Fig. 57. Stereogram showing microscopic structure of small intestine. Arteries, red; veins, blue; lymphatics, not colored.

Compound Tubular Glands are branched tubular glands which have a common duct that drains many branched tubes. The liver is a good example of a gland of this type.

Compound Alveolar Glands consist of a number of sacs whose ducts join and empty by a common duct. The structure of a gland of this type has often been compared to that of a bunch of grapes. Each grape represents an alveolus; the stem of the grape is the duct draining the alveolus; and the main stem of the bunch, where it is attached to the vine, corresponds to the duct of the gland. The pancreas and salivary glands are good examples of compound alveolar glands (Fig. 56).

Microscopical anatomy of the intestine. A study of the microscopical structure of the intestine of a vertebrate animal will serve to illustrate how various tissues are combined and correlated to form an organ. We find the intestinal cavity lined with a layer of cells known as the **mucosa** or **digestive epithelium,** under which is the **submucosa** (*sub*—under; *mucosa*) made up of connective tissue (Fig. 57). In the submucosa are delicate blood vessels. Under the submucosa, that is, toward the outside or periphery of the intestine, is found a layer of **circular muscles** whose fibers encircle the intestine, and outside these is a layer of **longitudinal muscles** whose fibers run lengthwise of the intestine. Covering the outside of the intestine is a layer of flattened cells (squamous epithelium) called **visceral peritoneum.**

It is interesting to note that the muscular arrangement just described is the same as that found in most tubular organs in the animal kingdom—circular muscles which contract to decrease the diameter of the cavity or lumen of the vessel, thereby elongating the vessel, and longitudinal muscles which contract to shorten the vessel and enlarge the diameter of the lumen. In the alimentary canal, the alternating contractions and relaxations of the muscle fibers in these two layers are responsible for the propulsive wave or series of waves known as **peristalsis** (*peri*—around; *stellein*—to place) which traverse the intestine and propel the food through the canal. This longitudinal-circular muscular arrangement is responsible to some extent for locomotion in the common earthworm, for the pumping action of the insect heart, and for the action of other tubular mechanisms found in the higher groups of animals. In general, also, if the organ or structure has a cavity, some type of epithelium will be found lining it.

The Process of Digestion

Various glands, built on the plans previously described, are associated with the alimentary canal, into which they pour their secretions which are the most important agents in the digestion of food. As in plants, the food is broken down, usually by hydrolysis, into simpler compounds. Digestion, which takes place in a cavity outside

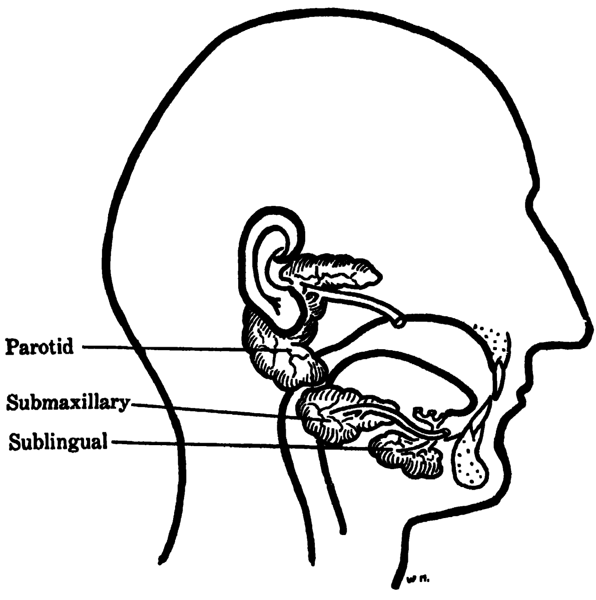


Fig. 58. Location of salivary glands.

the individual cells, as in the intestine, is known as extracellular digestion.

Digestive glands and enzymes. When food enters the human mouth it is lubricated by **mucus** secreted by unicellular glands in the epithelium lining the buccal cavity. It is thoroughly chewed by the teeth, moved about by the tongue, and thus mixed with **saliva,** which is poured into the buccal cavity from the **salivary glands** (Fig. 58). The salivary glands secrete mucus also.

The most important salivary glands are the **parotids,** located below and in front of the ears. These glands become painfully inflamed in mumps. The **submaxillary glands** lie between the halves of the lower jaw bone; and the **sublingual glands** lie beneath the floor of the mouth between the back of the tongue and the lower jaw.

The alkaline saliva pouring from the ducts of these glands contains, among other substances, an enzyme, **ptyalin,** which changes some of the starch to sugar. Digestion has now begun. The food is moved backward through the pharynx into the esophagus, down which it is propelled by paristalsis.

The esophagus delivers the food to the stomach, where it meets a new digestive fluid, the **gastric juice,** secreted from many compound tubular **gastric glands** in the stomach wall. Although the gastric juice is 99 per cent water, it contains **hydrochloric acid** and the enzymes **pepsin** and **rennin.** Pepsin, when activated by the hydrochloric acid, breaks down proteins into peptones and proteoses. Rennin causes the casein in milk to coagulate. Meantime the food is being thoroughly mixed by the churning action of the stomach muscles and eventually, as a semifluid called **chyme,** passes through the pyloric valve into the upper region of the small intestine known as the **duodenum.**

The duodenum receives secretions from two large glands, the **pancreas** and the **liver** (Fig. 53). The pancreas is a somewhat elongated, strap-shaped organ lying close to the stomach along the duodenum and secreting the **pancreatic juice,** which is carried to the duodenum by the **pancreatic duct.** The portion of the pancreas secreting the pancreatic juice is a compound alveolar gland. The liver, the largest gland in the body, is a reddish-brown lobed organ located somewhat to the right in the upper part of the abdominal cavity. Bile, the secretion of the liver, is stored in the pear-shaped **gall bladder,** whence it passes through the **common bile duct** to the duodenum at the point where it receives the pancreatic duct. In addition to the secretion of bile, the liver has other functions.

The food as it passes along through the small intestine is now acted upon by the alkaline pancreatic juice, which contains three important enzymes, **amylase, trypsin,** and **lipase.** Amylase continues the work begun by ptyalin in the mouth, changing starches to sugar. Trypsin acts on proteins, breaking them down into peptones and proteoses. Lipase changes the fats to fatty acids and glycerol. The action of bile in digestion is to accelerate the action of the pancreatic lipase in splitting fats. It also assists materially in the absorption of fats and neutralizes hydrochloric acid. Additional enzymes are contained in the intestinal juice secreted by hundreds of small glands in the intestinal wall. These enzymes are the sugar-splitting enzymes **maltase, invertase,** and **lactase,** and the proteolytic enzyme **erepsin,** which continues the protein digestion begun by pepsin and trypsin, forming amino acids.

The food is propelled along through the small intestine by peristaltic action. Digestion continues. Eventually the food passes through the ileocaecal valve into the large intestine. It is probable that no new enzymes are added here, but some of the digestive processes going on in the small intestine may be continued for a time. Further decomposition is effected by the action of bacteria. The real function of the large intestine is absorption, particularly of water; the large intestine also serves as a reservoir for the accumulation of unusable residues of foods. These final remains consist of undigested material, bile salts and pigments, and various secretions which eventually are evacuated through the anus.

Constipation. Haggard says, "If we may judge from the money expended in advertising laxatives, America is indeed a constipated nation." In view of the above statement, the following scientific findings should be kept in mind.

(*a*) There is considerable variation in frequency of bowel evacuation among different persons.

(*b*) The discomfort such as headache and dullness due to constipation are not the result of harmful bacterial toxins entering the blood from the colon, as many advertisements have it, but are due to the resultant nervous disturbances of reflex origin.

Region of the Alimentary Canal	Digestive Juice	Sources of Digestive Juice	Enzymes Contained	Kinds of Foods Acted upon	End Products of Digestion, the Traveling Forms
Mouth	Saliva	Salivary glands	Ptyalin	Starch	Malt sugar
Stomach *	Gastric	Gastric glands	Pepsin	Protein	Peptone and proteoses
		Walls of stomach	Rennin	Milk	
Small intestine	Pancreatic	Pancreas	Amylase	Starches	Malt sugar
			Lipase	Fats	Glycerol and fatty acids
			Trypsin	Proteins Peptones Proteoses	Some amino acids
	Intestinal juice	Intestinal wall	Erepsin	Peptides	Amino acids
		Intestinal glands	Invertase Lactase Maltase	Cane sugar Milk sugar Malt sugar	Simple sugars such as glucose
	Bile	Liver	None	Fats	Assists in digesting fats

* The stomach also secretes hydrochloric acid, which is not an enzyme but stimulates action of gastric enzymes and partly sterilizes the food.

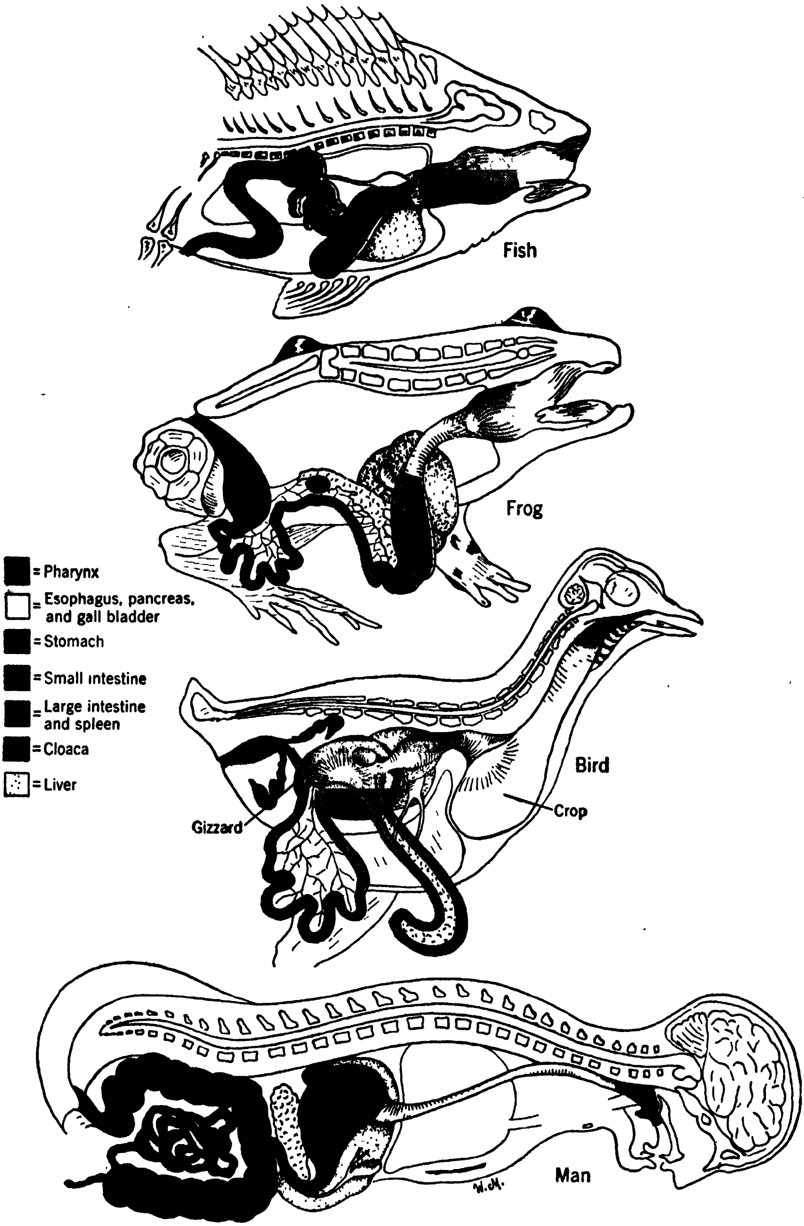


FIG. 59. Comparative study of the digestive tracts of different vertebrate animals.

(*c*) Most cathartics advertised are habit-forming drugs which lead to chronic constipation.

(*d*) Constipation is caused mostly by bad habits such as functional irregularity, poor posture, and diet deficient in roughage.

The table on p. 100 serves to summarize the essential facts of digestion and digestive enzyme action.

The Digestive Systems of Some Other Animals

The digestive systems of other backboned animals are essentially the same as man's, though variations are encountered (Fig. 59). In

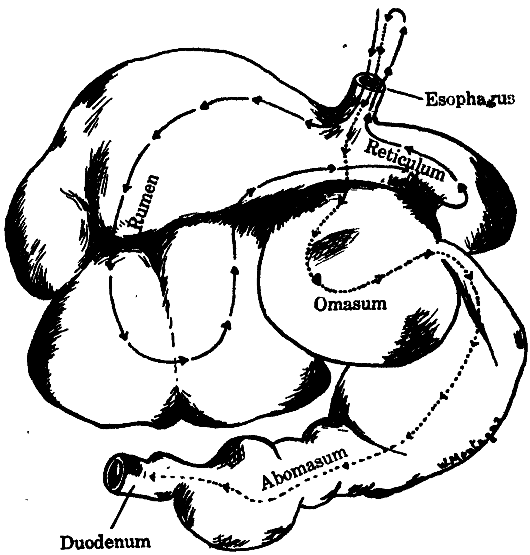


Fig. 60. Stomach of a ruminant or cud-chewing animal (cow). Course of food through the stomach is shown by arrows and dotted line. *Redrawn from Sisson, "The Anatomy of Domestic Animals." By permission of the publisher, W. B. Saunders Co.*

fishes there are passages known as **gill slits** leading from the pharynx to the exterior. The esophagus is much shortened, as would be expected in the absence of a neck. Frogs and their relatives have a short esophagus; also, the rectum, instead of opening to the exterior through the anus, discharges into a structure which receives not only the intestinal wastes but also the wastes of the kidneys, and the gametes from the genital organs (ovaries and testes) as well. Such a structure is known as a **cloaca** (*cloaca*—sewer). The cloaca opens

to the exterior through the **cloacal aperture.** It is present in certain fishes, reptiles, and birds.

In some birds the esophagus at its lower end is dilated to form a saccular **crop** used for food storage. The stomach is modified into a glandular region and a lower muscular-walled grinding organ, the **gizzard.** Two elongated **caeca** (blind sacs) lead from the intestine (Fig. 59).

Cud-chewing animals, like cows, have what is commonly called a four-chambered stomach (Fig. 60). However, the first three of these are really modifications of the esophagus, and the other is the true stomach. The first chamber of this so-called stomach is the **rumen** or **paunch.** Here the food is stored as it is eaten and then is gradually passed on to the **reticulum,** the second chamber, where it is softened by further mixture with digestive fluids. Later small rounded masses of this food are passed back up to the mouth, where, as the cud, it is thoroughly chewed and mixed with saliva. It is then passed to the third compartment, the **omasum,** and then into the **abomasum,** where characteristic gastric digestion takes place.

The digestive glands of the various vertebrate animals are similar except for the salivary glands, which may vary in number or be missing. The student should study Fig. 59 carefully and compare the digestive tracts of certain backboned animals. In the lower animals there is a wider range in the variations of the machinery of digestion.

Absorption

As we have seen in plants, the purpose of digestion is not only to break food down into simpler compounds but primarily to render it soluble and diffusible so that it can be transferred to various parts of the plant. Digestion serves the same function in animals. It must be realized that each one of the millions of cells making up the organism must have its supply of food for the replacement of that consumed in living. As we have just seen, the food in the small intestine is now broken down and soluble. It is ready to be taken from the intestine and distributed to these millions of needy cells. The real task in food distribution, as we shall see in the following pages, is accomplished by the blood. But the food must be transferred from the intestinal tract into the blood stream. It must be absorbed.

Although water is absorbed in the large intestine, most of the food absorption in man and the higher animals takes place in the small intestine. In the limited space of the body cavity, and more particularly in the intestine itself, various modifications occur that in-

crease surface (Fig. 61). It is a self-evident fact that a square yard of cloth will absorb more moisture than a square inch. The modifications that increase the surface area of the intestines increase both the amount of absorption and the speed with which absorption takes place. In the walls of the stomach there are many folds. In the

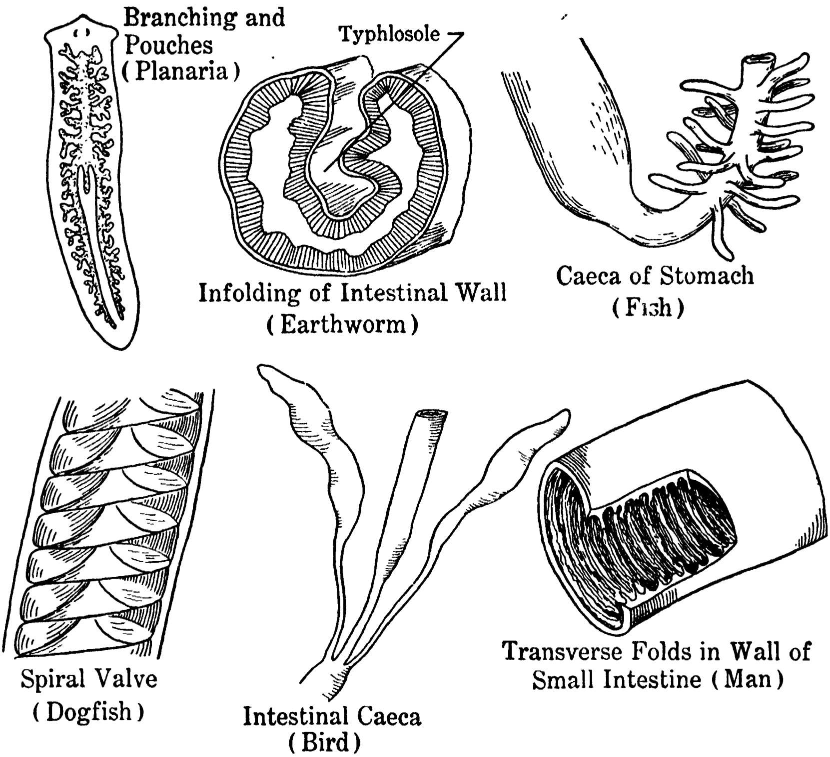


FIG. 61. Different devices that increase absorptive surfaces of the digestive tracts of various animals.

human intestine there are, in addition to folds, millions of minute projections called **villi** (*villus*—hair) (Figs. 57 and 62). In the intestine of certain sharks the food travels down a sort of spiral staircase, an arrangement called a **spiral valve** (Fig. 61). In the earthworm the dorsal wall of the intestine is infolded along its length; this internal fold is called the **typhlosole.** In the large intestine of man the wall is constricted at intervals, forming saclike pockets. All these modifications greatly increase the surface.

The villi not only greatly increase the digestive surface but at the same time bring countless tiny blood and lymph vessels into close

contact with the inner absorbing epithelium of the intestine (Fig. 62). The lymph vessels of the villi, or the **lacteals** (*lac*—milk), absorb the products of the digested fats. The lacteals converge into increasingly larger **lymph vessels,** which eventually unite to form a main vessel, the **thoracic duct,** that empties directly into the blood stream anterior to the heart. The venous capillaries absorb the digested proteins and carbohydrates. The veins course through the

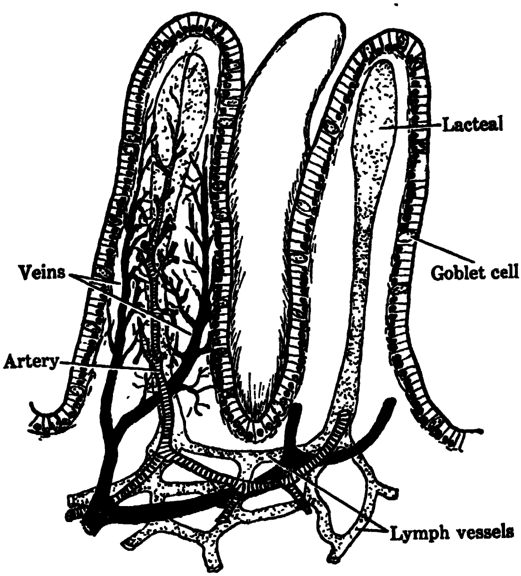


FIG. 62. Diagram of villi, showing distribution of blood and lymph vessels.

mesentery of the intestine and eventually lead into one main vessel, the **portal vein,** which branches through the liver. Here some of the carbohydrates are stored in the form of **glycogen,** or animal starch.

Glycogen is stored in the liver and also in other parts of the body. The liver acts on the amino acids which come from the intestine, breaking them down still further and removing the nitrogen in the form of **urea.** This process is called **deamination.** From the blood the liver absorbs many toxic substances and converts them into nontoxic ones.

The absorption of foods from the intestines apparently involves more than the simple processes of diffusion and osmosis; it "depends largely upon the properties of the separating wall of epithelial cells." In other words, the living membrane furnishes energy that aids in absorption.

Solving the Riddle of Digestion

From what has just been said of digestion, one may get the impression that all is known about this process and that this knowledge was easily acquired. This impression would be far from the truth. The partial solving of this riddle has taken the tireless efforts and lifetime studies of intelligent, earnest men.

About the middle of the eighteenth century a Frenchman, Réaumur, fed his pet kite (a species of hawk) some meat inclosed in metal tubes, the ends of which were closed with fine gratings. Later these indigestible pellets were ejected through the mouth and the inclosed meat was found to be partially dissolved. Vegetable matter thus fed was found to undergo no change. Réaumur later sent these tubes on another errand, but this time they were filled with pieces of sponge which brought up a yellowish fluid that had a bitter taste. This fluid was found to act on food placed in glass vessels. Thus began the scientific study of digestion. Later, an Italian, Spallanzani, said that human digestive juice would melt food even though it was outside of the body. In those days this seemed remarkable because digestion was taking place without the "vital influence" of the stomach. Spallanzani, continuing his studies, found that saliva would act on starchy foods even outside the body. However, there were many who refused to believe. Typical of the arguments of these diehards was Hunter's declaration that "some physiologists will have it that the stomach is a Mill; others that it is a fermenting vat; others that it is a Stew Pan; but in my view of the matter it is neither a Mill, a fermenting Vat, nor a Stew Pan—but a Stomach, gentlemen, a Stomach."

About 1825, our understanding of digestion really began to advance with Dr. Beaumont's experiments on a man named St. Martin. St. Martin accidentally shot himself in the stomach. Beaumont sewed the edges of the stomach to the skin. St. Martin got well, although he now had a hole in his stomach and abdomen. Through this hole Beaumont could see the stomach move and digestive juice pour out. He thought he would see how this gastric juice worked. Through the opening he stuck some meat tied to a string, and two hours later pulled out the string. The meat had entirely dissolved! Later, by means of a rubber tube, he extracted from the stomach some gastric juice which on analysis was found to contain hydrochloric acid. These and other studies of Beaumont are classics in the early history of the study of digestion.

Other interesting experiments on digestion are those of Pavlov, a Russian, and those of Carlson, an American. Carlson's "experimental animal" was a man whose esophagus was so badly burned with lye that he had to be fed by a tube leading directly through the abdo-

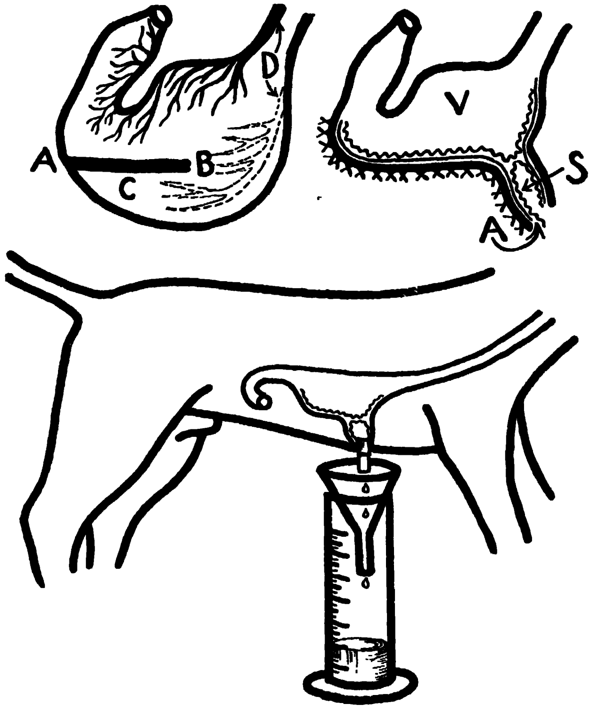


FIG. 63. Drawings showing Pavlov's method of making a gastric pouch. *A*, incision *A–B* is made in the stomach wall, leaving a flap, *C*, which is turned down so that pouch *S* forms an isolated miniature stomach in the side of main stomach *V*. Lower drawing shows the method by which gastric juice is drained from the miniature stomach *S* while digestion is going on in the main stomach. *Redrawn from Best and Taylor, "The Living Body," by permission of the authors and publisher, Henry Holt and Co.*

men to the stomach. In this way Carlson was able to study the amount of flow of the gastric juice when the man smelled appetizing and nonappetizing food. The reactions in the stomach caused by the sight of foods and the chewing of food were observed and measured. These observations showed that the flow of digestive fluids is influenced by nervous reaction and that the digestive machinery begins to operate before the food ever enters the mouth. By cutting out of the duodenum of a dog a section containing the opening of

the pancreatic duct, and sewing the piece to the body wall in such a way that the duct opened to the outside, Pavlov was able to study the amount of flow and the nature of the pancreatic juice (Fig. 63). The dog under careful dieting continued to live. The pancreatic juice could thus be collected and analyzed, and its digestive action could be studied. Dogs have been found to secrete 200–750 cc. of pancreatic juice per day. Many of the important facts of digestion have been uncovered by other ingenious experiments on the lower animals, particularly dogs, cats, and guinea pigs.

The role of the various intestinal regions in absorption has been determined by removing the small intestine and attaching the stomach directly to the large intestine. The importance of the large intestine has been learned by its removal, or by making an outlet for the small intestine so that the food was unable to reach the large intestine. It would be possible to describe many other interesting and ingenious experiments which man has made in his efforts to solve the riddle of digestion.

FOODS AND THEIR USES—NUTRITION

As we have previously pointed out, all organisms in order to live must have an adequate food supply. Man is no exception. Naturally the choice of food varies with the animal. Some feed entirely on vegetation and are called **herbivorous** (*herba*—herb; *vorare*—to devour); others depend entirely upon the flesh of other animals for food and are said to be **carnivorous** (*caro*—flesh; *vorare*). **Omnivorous** (*omnis*—all; *vorare*) animals eat both fleshy and herbaceous food. The choice of food is determined by several factors, among which may be listed climatic conditions and availability. Animals in northern latitudes require more heat to withstand the cold than those in the tropics. This heat is furnished by the supplies of energy stored in the fats of other animals. For example, the Eskimo eats blubber because he needs it and because it is readily available. Environment also plays its part in determining food habits. The food of aquatic animals differs from that of land forms. The animal pattern or form influences food choice; for example, the food of an oyster is very different from that of a tiger. So far as we know man is the only animal which should be able to select food intelligently to satisfy energy and structural needs. In the centuries past, man was guided by his "stomach" rather than his brain in the selection of his menu. This is still true for many people of today, but in the light of modern knowledge of nutrition it is time to change guides.

Energy value of food. One of the earliest studies of nutrition was made by Sanctorius in 1614 (Fig. 64). He weighed himself before and after meals to find how much of the food eaten vanished in the form of "insensible perspiration" and "heat." Other investigators discovered that the food was oxidized in the body, releasing energy, and that the energy content of foods could be measured.

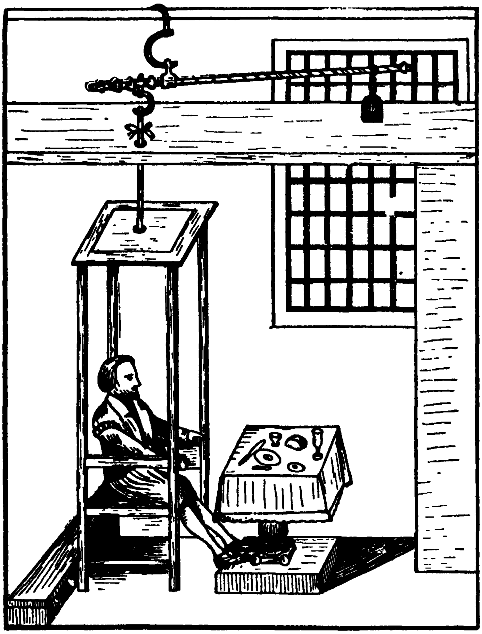


FIG. 64. How Sanctorius tried to count calories in 1614. *After Jean, Harrah, Herman, and Powers, "Introductory Course in Science for Colleges, II." By permission of the publisher, Ginn and Co.*

The unit of measurement adopted was the **Calorie** (*calor*—heat). A food Calorie is approximately the amount of heat required to raise one kilogram of water one degree centigrade.

After the establishment of this unit of energy the next step was to measure the energy values of known weights of various foods, particularly the carbohydrates and fats. Protein has been found to be expensive as an energy food, but it is needed for the replacement of certain components of the organism which are continually being torn down and lost.

A certain amount of energy is necessary to keep an animal living, even during complete relaxation and repose. This amount of basal energy or minimal heat produced is the measure of the **basal metab-**

olism of an organism (Fig. 65). It varies with the weight of an animal, but for each square meter of body surface exposed, it is practically the same in all mammals. It can be readily seen that, in addition to the basal metabolic requirements, man needs fuel to provide energy for his occupation and recreational activities (Fig. 65).

For an individual of given weight the number of Calories required varies with age, occupation, and recreational habits. For those en-

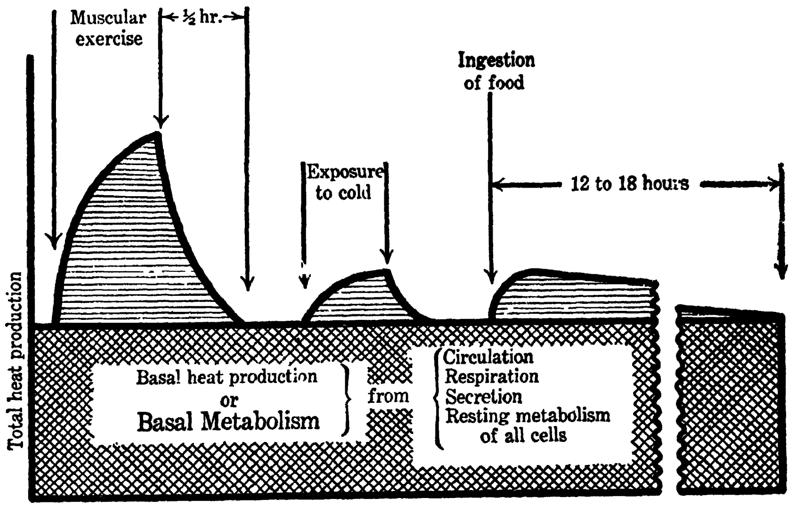


FIG. 65. Factors modifying heat production in warm-blooded animals. There is the basal heat production plus heat derived from muscular exercise (part of which heat is liberated after exercise is stopped), from exposure to cold, and from ingestion of food. *Redrawn from Carlson and Johnson, "The Machinery of the Body." By permission of the publisher, University of Chicago Press.*

gaged in sedentary occupations the daily requirement varies from 2,200 to 2,800 Calories; an individual who does manual labor with pick and shovel will require daily from 4,000 to 6,000 Calories. If man is to balance his food according to his needs, it will be necessary for him to have some accurate measurement of food values in Calories to satisfy his daily requirements.

Water and minerals. The importance of water to the organism has already been pointed out. In addition to water, proteins, carbohydrates, and fats, the organism must have certain minerals. In the higher animals calcium and phosphorus are especially necessary for bone and teeth formation. Calcium is necessary for the clotting of blood, and it aids in muscular regulation. In such lower animals as

oysters and clams, calcium is necessary for shell formation. Iron is a necessary constituent of the hemoglobin or red part of the blood. Copper in minute amounts serves as an aid to iron utilization, although it is not a constituent of hemoglobin itself. As will be seen later, iron is very necessary to insure normal growth and development. Phosphorus, calcium, magnesium, sodium, and potassium, in the form of various salts, perform an important function in regulating the acidity and alkalinity of the blood.

VITAMINS

Modern science has demonstrated that man does not live by bread alone nor by any fixed quota of carbohydrates, proteins, fats, and minerals. Substances called **vitamins** (*vita*—life; amine) play an important part in man's nutritional program and undoubtedly do the same for all other animals and for plants, though our knowledge of their role for other groups is slight compared to what we know of it in man, rats, mice, guinea pigs, and various domesticated animals.

Long ago it was recognized that certain foods were beneficial for various diseases. In 1720 Kramer was of the opinion that scurvy could not be cured by medicine or an operation. He wrote: "But if you can get green vegetables; if you can prepare a sufficient quantity of fresh, antiscorbutic juices, if you have oranges, lemons, citrons, or their pulp and juice preserved with whey in cask, so that you can make a lemonade or rather give to the quantity of 3 or 4 ounces of their juice in whey, you will, without other assistance, cure this dreadful evil."

In 1912, Funk found that he could cure polyneuritic pigeons by a substance which he extracted from bran. Funk finally gave the name **vitamin** to these new principles which today, after years of research, have been designated by the letters of the alphabet as vitamins A, B_1, B_2, C, D, E, and K. The basic source of vitamins is the plants, which supply not only the vitamin itself but often the precursor from which the vitamin is built. Vitamins and their precursors are found in various parts of the plant, such as the leaves, roots, and fruits. Lack of vitamins in the diet of man and other animals often causes non-infectious diseases called **deficiency diseases.**

In the early days of vitamin research, the chemical structures of these substances were unknown, so they were labeled vitamin A, vitamin B, and so on. Today the chemical formulas of most of them

are known, and the majority of them have been synthesized in the chemist's laboratory. Water-soluble vitamin B is now known to consist of at least eight or more food factors! So in the light of modern research it has been suggested that it might be better to list these essential food factors by using their chemical names rather than the old terms.

Vitamin A ($C_{20}H_{30}O$). The precursor of this vitamin occurs in plants in the form of a pigment called **carotene.** The animal obtains carotene from its green vegetable food and converts it into vitamin

Fig. 66. Xerophthalmia in white rat caused by a diet deficient in vitamin A, and recovery when given vitamin A. *By permission of Mead Johnson & Co.*

A. It has been extracted in the pure form from fish liver and has been synthesized in the chemical laboratory.

Lack of vitamin A, or carotene, in the diet may result in disturbances in the epithelial tissues. Often the skin may become dry or horny, a condition known as **keratinization,** which also affects the alimentary canal, respiratory tissues, and the genito-urinary tract. Frequently the front of the eye becomes rough and dry, a condition called "dry eye" **(xerophthalmia),** and as a result the eye may become a ready prey for infection (Fig. 66). After a famine this condition has been very prevalent among children in various parts of the world, particularly in India and Japan. The first indication of vitamin A deficiency is a type of **night blindness,** that is, a partial loss of sight in dim light. During the earlier stages in the life of the individual, the absence of this vitamin may indirectly affect growth. There is no conclusive evidence, however, that vitamin A may assist in building up resistance to common colds although it may shorten the duration of the attack.

Some of the principal sources of carotene are: raw carrots, lettuce, tomatoes, cantaloupes, sweet potatoes, and most yellow fruits and vegetables. The vitamin itself is found in oysters, egg yolk, liver,

butter, and fish-liver oils such as cod-liver oil and halibut-liver oil. Carotene is found also in numerous other leafy vegetables, fruits, and corn, as will be seen in the chart at the end of the chapter.

Vitamin B_1. Vitamin B_1 and other factors of the vitamin B complex usually occur together. Vitamin B_1 is also known as **thiamine** ($C_{12}H_{17}N_4OSCl$). B_1 was one of the first vitamins to be discovered. Eijkman, a Dutch physician who lived in Java, observed many cases of an Oriental paralytic disease known as **beriberi,** which translated means "extreme weakness." People afflicted with beriberi find their muscles becoming stiff and painful. Neuritic pains caused by in-

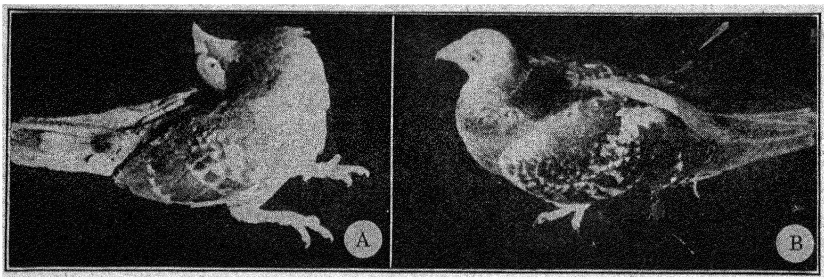


FIG. 67. Polyneuritic pigeon. *A,* afflicted bird; *B,* same bird after recovery following feeding with food containing vitamin B_1. *By permission of Merck and Co.*

flammation of the nerves occur, and eventually the patient may become completely paralyzed as a result of degeneration of the nervous tissue. Under experimental conditions, lack of thiamine in man's diet results in irritability, inertia, and such early onset of fatigue that individuals cannot carry on their daily work. There is also loss of appetite.

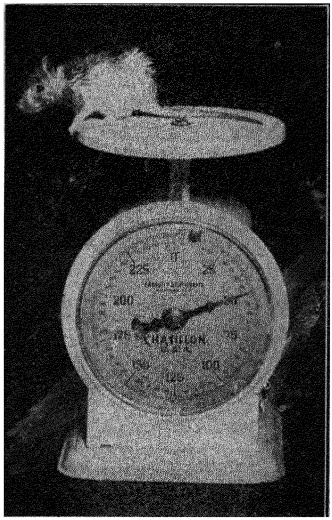
For a time the remedies applied consisted mostly of exercise and improved sanitation. In 1897, Eijkman noticed that fowls fed on polished rice—rice with the hull removed—were afflicted with the disease called **polyneuritis,** a disease very similar to beriberi, but that those fed on the whole grain were normal (Fig. 67). This discovery opened the way for the study of human beriberi, and, to make a long but interesting story short, it was discovered that the hull of the grain contained something which prevented this disease—another case where coarse food is better than refined. Thus whole-wheat bread is more healthful than white.

Vitamin B_1 is also a necessary component of plant cells, and the higher plants manufacture it, storing relatively large amounts in the seeds. Without the influence of vitamin B_1 the germinating seed cannot form a root system.

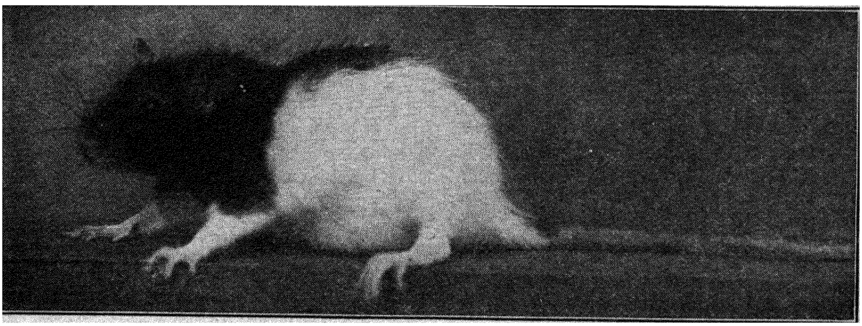
Formerly it was claimed that, by adding vitamin B_1 to the soil, the gardener could grow "five-inch rose buds, daffodils bigger than a salad plate, and snapdragons six feet tall." More recent experiments indicate that "vitamin B_1 has been badly exploited, and that it has no value as recommended for horticultural practice."

Vitamin B_1 is found in a number of foods: raw cabbage, raw carrots, lettuce, whole-wheat bread, pork, beef, mutton, and eggs. Since it is soluble in water and is also destroyed by heat, food cooked in water tends to lose vitamin B_1.

Vitamin B complex. The vitamin B complex really consists of twelve or more vitamins including what was formerly called vitamin G. Of these vitamins, **riboflavin** ($C_{17}H_{20}N_4O_6$). is one of a group of yellow substances found in many plant and animal tissues. If riboflavin is lacking in man's diet there result a reddening of the eyes owing to the development of visible, fine blood vessels in the cornea and an intolerance to bright light. Dogs, rats, and chicks whose diet is deficient in riboflavin lose weight (Fig. 68).



A



B

FIG. 68. *A,* rat fed for seven weeks on a diet deficient in riboflavin gained only 15 grams, whereas a normal rat (*B*) given a balanced diet gained 90 grams in the same period. *By permission of Mead Johnson & Co.*

Nicotinic acid (C_5H_4NCOOH), or **niacin,** is the most important B complex factor for treatment of pellagra. In 1917–1918 there

were over two hundred thousand cases of pellagra mostly in the southern United States, and in 1935 more than three thousand people died of this disease. Some of the symptoms of the disease are soreness of the mouth and tongue, followed by digestive disturbances, and a peculiar bronze color of the skin, particularly where the sun strikes it. The discolored areas are ready sources of infection. In the later stages of the disease there may be nervous twitchings and disorders. Irrespective of the specific preventive substances concerned, it is known that a diversified diet with milk, salmon, lean meat, and plenty of green leafy vegetables prevents and cures the disease.

Another vitamin, **pyridoxine** ($C_8H_{11}NO_3$) or vitamin B_6, prevents a reddening and scaliness of the skin and loss of hair in rats. Lack of it affects growth in chicks.

Biotin (formerly known as vitamin H) is apparently a growth-promoting vitamin although its role is not well understood. It is found abundantly in growing tissue and in tumorous growths. It is essential for the growth of yeast and other microorganisms.

Vitamin C. The disease **scurvy** has been known for a long time. The patient afflicted with scurvy has bleeding gums, loosened teeth, swollen joints, and brittle bones; the blood vessels rupture easily, those in the skin leaving red blotches. The individual becomes "lazy." Plagues of this non-infectious disease were frequent among people in the more northern countries and among sailors who made long voyages on the slow-going sailing ships. It was the bane of Arctic explorers.

About 1757, Lind, a British surgeon, discovered that citrus fruits contained something that prevented this plague, and so the British navy included lime juice in its rations. Today we know this antiscorbutic substance as vitamin C, which can be extracted in pure form and can be synthesized in the chemist's laboratory. It is now known as **ascorbic acid** or **cevitamic acid** ($C_6H_8O_6$). Apparently the only species of animals that need vitamin C are man, monkeys, and guinea pigs. Other animals seem to be able to synthesize the substance from certain dietary components.

Vitamin C is abundant in lemons, limes, oranges, and such raw vegetables as cabbage, lettuce, spinach, tomatoes, and peppers. It is practically lacking in foods of animal origin. Cooking and canning, except of acid foods, usually result in loss of vitamin C.

Vitamin D. Through the centuries a condition known as rickets ("twists") has been present in the human population. The condition was, and is, particularly prevalent among the poor children in large

and crowded cities. Rickets usually appears in children under two years of age and affects markedly the bones, especially those of the arms and legs, which become abnormally soft because of a lack of calcium. In this weakened, non-rigid condition, they tend to twist and bow (Fig. 69). In rickets, the head of the individual becomes abnormally large and the forehead bulges. Because of the malformation of the ribs, the chest narrows to form a so-called "pigeon chest." The teeth are also affected.

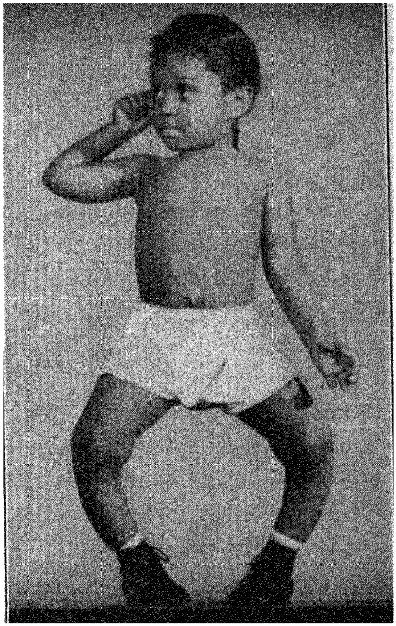


FIG. 69. A case of rickets caused by a diet deficient in vitamin D. From film, *"Foods and Nutrition," Encyclopædia Britannica Films, Inc.*

Rickets is found not only in man but also in dogs, chickens, and other domestic animals. Mellanby, an Englishman, discovered that rickets in dogs was due to a diet deficiency. Later McCollum, an American, demonstrated that rickets in man was caused by lack of some vitamin factor.

Rickets is a disturbance of the calcium and phosphorus metabolism of the body, and the structures richest in these substances are most affected. We now know that vitamin D holds calcium and phosphorus in the body and so regulates both the necessary calcification of the bones and teeth and the normal functioning of the muscles and the nervous system. Incidentally, this vitamin is necessary for numerous functions in other animals. In poultry a lack of it causes a decrease in egg production, and in cows, lactation is affected.

Vitamin D is not so widely distributed in nature as the other known vitamins. Food substances most rich in vitamin D are egg yolk, cod-liver oil, and other fish oils. There is a variable amount in butter. It had been observed that rachitic children, when exposed to sunlight, were definitely benefited, and, in some of them, the defect was prevented if the sunlight treatment was begun in time. In 1919 it was demonstrated that exposure to ultraviolet light would cause a deposition of calcium in the bones of rachitic animals

and cure the disease. Later it was demonstrated that food materials could be made antirachitic by exposing them to ultraviolet light. Further experimentation revealed that the sterols, a type of lipids found in certain fish-liver oils, contain some precursor which, when irradiated, became the effective agent of vitamin D. The activated sterol, **ergosterol,** is the most important commercial source of vitamin D. There occur several forms of vitamin D in nature, all of them closely related chemically.

It now appears that in most animal bodies there is present a precursor of vitamin D which becomes active under the influence of the ultraviolet rays of the sun. Thus vitamin D can be synthesized in the human skin and apparently in the hair of cattle. Cattle kept in the pasture fields during the summer never need to have their diet enriched by vitamin D. The body need not be in direct sunlight to be benefited, for light from a northern sky and reflected rays from snow and water are also effective. However, certain types of window glass, clouds, smoke, and dust effectively cut off these activating rays of the sun.

From what has been said, we see that control of rickets is a problem which involves not only biology as it concerns food but also sociology and economics, including such factors as crowding of population, housing, and community planning. There must be proper spacing of houses and control of excess smoke which filters out the necessary rays of the sun.

Vitamin E. It has been found that rats fed on a diet lacking this component do not reproduce. The reproductive tissues are found to be degenerated in males, and in pregnant females the young fetuses die and are resorbed. Although the females can be cured by the addition of vitamin E to their diet, the males never regain their reproductive capacity. It has been definitely proved that vitamin E is essential for normal reproduction in rats, mice, and poultry. There is no definite evidence of its effect upon humans.

Vitamin E is found in the green forage of domestic animals and is abundant in the germ of cereal grains as well as in cottonseed oil and corn oil. Vitamin E is a sterol which has been isolated as **tocopherol** ($C_{29}H_{50}O_2$). It is not readily destroyed by heating or cooking, but it is destroyed if the oil containing it becomes rancid.

Vitamin K ($C_{31}H_{46}O_2$). This is the anti-hemorrhagic vitamin which is found in such vegetables as spinach, cabbage, and other green foods. Its presence prevents bleeding diseases caused by a lack of prothrombin, a substance found in the blood and necessary to bring about clotting. It is needed especially by farm animals but

is not so important in man unless the bile does not enter the intestine, under which circumstances there is a tendency to bleed if an operation is performed. Vitamin K is used to correct the hemorrhagic diseases of the newborn.

The investigations in the vitamin field are exceedingly numerous, and new discoveries are being announced frequently. So rapid is the development in this field that, even by the time these words are being read, new discoveries may demand a revision of the statements.

Vitamin propaganda. Since their discovery, much has been said, written, and taught about vitamins, some of which has been true, some unintentionally misleading, and some misinformation broadcast deliberately for commercial gain. Vitamins share with hormones the advertising spotlight in patent-medicine advertising. True, vitamins A, B_1, B_2, C, D, and perhaps E are necessary to maintain normal health and prevent certain diseases. Adequate amounts of these vitamins can be obtained in the ordinary average diet, and only under exceptional conditions is it necessary to secure a more than usual supply by the use of commercial preparations. Under these circumstances, it is best to get the advice of a physician.

A chart summarizing information about certain vitamins follows.

VITAMINS—CHEMISTRY, SOURCES, EFFECT OF DEFICIENCY

Vitamin	Source xxx—abundant xx—good	Chief Results of Deficiency in Diet
A $C_{20}H_{30}O$ Precursor—carotene (p. 111)	Cod-liver oil xxx Halibut-liver oil xxx Carrots, raw xx Lettuce xx Tomatoes xx Cantaloupe xx Pineapple xx Egg yolk xx Butter xx	Keratinization of epithelial tissues. Liability to infection of the skin. Night blindness. Failure of growth.
B_1 $C_{12}H_{17}N_4OSCl$ Thiamin chloride (p. 112)	Cabbage, raw xx Carrots, raw xx Lettuce, raw xx Potatoes, raw xx Tomatoes, raw xx Rice, unpolished xx Wheat, whole xx Meat xx Egg yolk xx Cornmeal xx	Beriberi in man. Polyneuritis in birds. Growth affected. Essential to utilization of carbohydrates. Aids appetite and digestion.
B complex $C_{17}H_{20}N_4O_6$ Riboflavin (p. 113)	Green, leafy vegetables xxx Liver xxx Kidney xxx Other meats xxx Egg yolk xxx Milk, whole xxx Cornmeal xxx	Not found in man under natural conditions. Lack in man causes fissures and cracks at angles of mouth, and itching, burning of eyes, and poor vision. Dogs and chicks lose weight. Cataract in cats. Pellagra (?).

VITAMINS—CHEMISTRY, SOURCES, EFFECT OF DEFICIENCY (Cont.

Vitamin	Source xxx—abundant xx—good	Chief Results of Deficiency in Diet
C $C_6H_{10}O_6$ Ascorbic or cevitamic acid (synthesized) (p. 114)	Cabbage, raw xxx Lettuce xxx Potatoes, raw xxx cooked xx Citrus fruits xxx Carrots, raw xx Celery, raw xx Cucumbers, raw xx Peas and beans xx Other fruits xx	Scurvy.
D Precursors Sterols, particularly ergosterol Sunlight (p. 114)	Egg yolk xxx Cod-liver oil xxx Halibut-liver oil xxx Butter xx Oysters xx	Rickets in both man and domestic animals. Diminishes egg production in poultry. Necessary for normal function of muscles and nerves.
E $C_{29}H_{50}O_2$ Tocopherol (p. 116)	Lettuce xxx Tomatoes xx Beef xx Egg yolk xx Butter xx	No definite evidence of effect on man. Necessary for reproductive capacity of rats, mice, and poultry.
K $C_{31}H_{46}O_2$ (p. 116)	Spinach xxx Cabbage xxx Other green fruits and vegetables xx	Blood does not clot owing to lack of prothrombin in certain liver diseases in man. Hemorrhagic diseases in the newborn.

SUMMARY

The rate of chemical reactions involved in digestion is accelerated by catalysts called enzymes. These are probably protein substances of colloidal nature produced by living cells. They work best at medium temperatures. Enzymes are inactivated by low temperatures and are completely destroyed by high temperatures. Enzymes speed up or retard reactions and may even initiate them. They are not used up in the reaction and form no part of the new substance produced. Small amounts of enzyme serve to change very large quantities of the substrate. They are probably as important in catalyzing synthetic reactions as they are in changing the rate of hydrolyses. They are quite specific in their action, each one being rather definitely related to some particular kind of reaction in a given substance.

Enzymes are present in all plant tissues, and the digestive processes may take place within the cell (intracellular) or outside the cell (extracellular). Carnivorous plants trap insects that when digested supply nitrogen to the plant. Extracellular digestion by means of

excreted enzymes hydrolyzes the proteins of the insects, and the end products containing nitrogen are absorbed by the plant cells.

Animals as well as plants have specialized structures for metabolism, and, just as in the plant, digestion of food takes place by means of enzymes. In animals the food enters the alimentary canal. As it passes down this tube it is acted upon by different enzymes secreted by various glands located in the walls of the digestive canal. Other digestive juices from associated glands, such as the liver and pancreas, are poured into the tube. The digestive canal and its associated structures are made up of combinations of various types of epithelial, muscular, and supporting tissue. Some nervous tissue is also present. The glandular structures are usually of the tubular or alveolar type. In the small intestine the digested food material is absorbed by the tiny blood and lymph vessels.

Foods include not only carbohydrates and fats for energy values but also proteins for building and replacing structures. Water and minerals are necessary in varying amounts, and last but not least are those important regulatory factors in the diet—the vitamins.

CHAPTER V

METABOLISM (*Continued*). HOW IS FOOD TRANSPORTED AND DISTRIBUTED?

We have previously stated that the cell is not only the structural unit of the organism but also the functional or physiological unit, and that the life and behavior of the organism are in a measure the result of the actions and reactions of its living component cells. Every living cell then must carry on metabolism, which means that the countless millions of cells must be supplied with new materials to replace those used up, and waste must be removed. The higher plants have a transportation system consisting of vessels or ducts. We have seen that xylem transports raw materials from the root up through the stem to the leaf, and that a liquid, rich in manufactured plant food, is carried along through the sieve tubes of the phloem. Thus the cells of the plant receive their food supply.

The same metabolic problem is present in every living animal cell. In order to live, it must be supplied with certain materials and wastes must be carried away. To meet these requirements efficiently a transportation system through the organism is needed which will serve every cell either directly or indirectly. In animals these transportation systems are the blood and lymph circulations together with their systems of vessels and spaces (sinuses or hemocoeles).

THE CIRCULATORY SYSTEM

Vessels. The circulatory system is made up of the **heart** and a system of vessels. The rhythmic contractions of the heart maintain a flow of blood *out through the* **arteries,** which are vessels with fairly thick walls (Figs. 70 and 71). The arteries branch and subdivide, gradually decreasing in diameter until they empty into minute vessels called **capillaries** (*capillaris*—hair). The capillaries branch, extending into intercellular spaces of all the organs and tissues and forming a continuous network through the organism. Their thin walls—they are composed of but a single layer of flat epithelial cells —allow ready exchange of materials between the blood and the

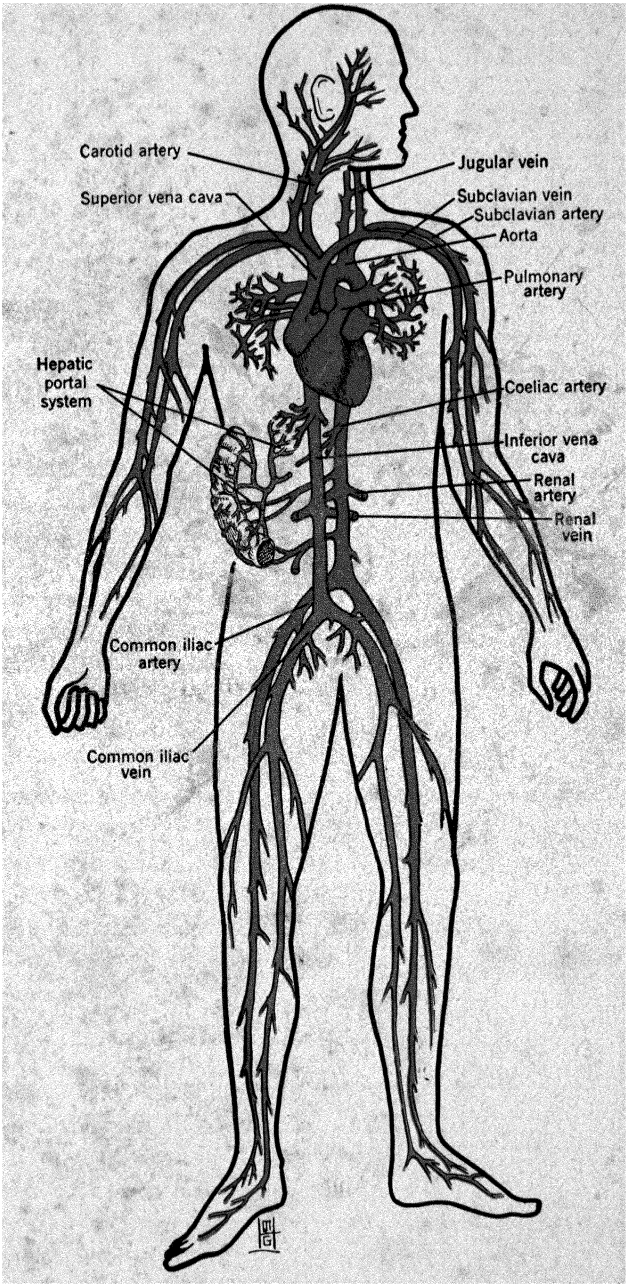


FIG. 70. Diagram illustrating the circulation paths of man. Arterial system in red; venous system in blue; hepatic portal system in purple.

various cells of the body by diffusion and osmosis. These capillaries unite to form small vessels called **veins,** which have thinner walls than the arteries (Figs. 70 and 71). These veins in turn join to form larger veins, which carry the blood back to the heart, thus completing the circulation.

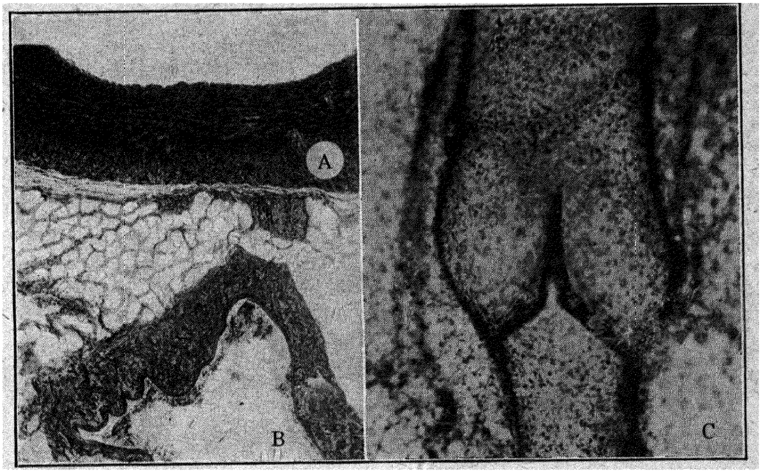


FIG. 71. *A,* portion of the wall of an artery. *B,* portion of the wall of a vein. Notice the difference in thickness. *C,* longitudinal section of lymph vessel showing a valve. Note the thin walls. *Photomicrographs by permission of the General Biological Supply House.*

It is estimated by Dr. Krogh, who was awarded the Nobel prize for his studies of the human circulation, that, if all the capillaries in the body of an average man were cut and spread open, the total surface exposed would cover a city block. If the capillaries were placed end to end with the other blood vessels, we would have a string of blood vessels which would encircle the earth two and one-half times.

The heart. The human heart is a thick-walled muscular organ lying inside the **pericardial cavity,** which is enclosed by a tough sac of connective tissue, the **pericardium** (*peri*—around; *cardia*—heart) (Fig. 72). The heart is divided into four compartments: the **right auricle** (*auricula*—little ear), **left auricle, right ventricle,** and **left ventricle.** The walls of the ventricles are much more muscular and thicker than those of the auricles. The right auricle and the right ventricle are completely separated from the left auricle and the left ventricle. The **venous blood,** often but incorrectly spoken of as the "impure" blood because of its low oxygen content, is collected from the body and poured into the right auricle. A wave of muscular contraction originating in the wall of the right auricle sweeps down

across the two auricles and thence over the ventricles, causing a muscular contraction of the heart which seems to twist and wring the blood from it. This is the heart beat. The right and left sides of the heart are contracting simultaneously. However, in order to

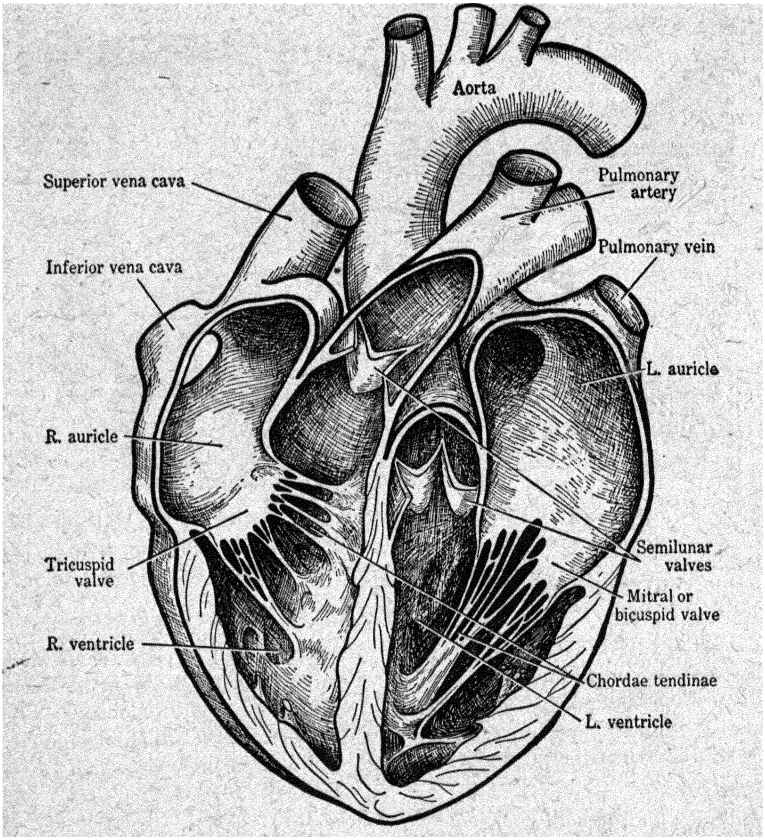


FIG. 72. Diagram showing the internal anatomy of the heart. *Redrawn from Haggard, "The Science of Health and Disease." By permission of the publishers, Harper and Brothers.*

present a clearer understanding of its mechanism, each side of the heart will be discussed separately.

The blood, acted upon by gravity and the muscular contraction of the walls of the right auricle, flows through an opening over flaps of tough connective tissue, the **tricuspid valve** (*tri*—three; *cusp*—tooth) (Fig. 72). The increased pressure on the blood as the ventricle contracts pushes the three flaps composing the tricuspid valve away from the heart wall and against each other, thus closing the

opening between the auricle and the ventricle (Fig. 73). All the valves of the heart operate on this same general principle. When the right ventricle contracts, the tricuspid valve closes and the blood is forced out through another opening into a vessel, the **pulmonary artery** (*pulmo*—lung), which leads to the lungs. At the opening of the pulmonary artery into the right ventricle there are three small, half-moon-shaped pocketlike flaps, **semilunar valves** (*semi*—half;

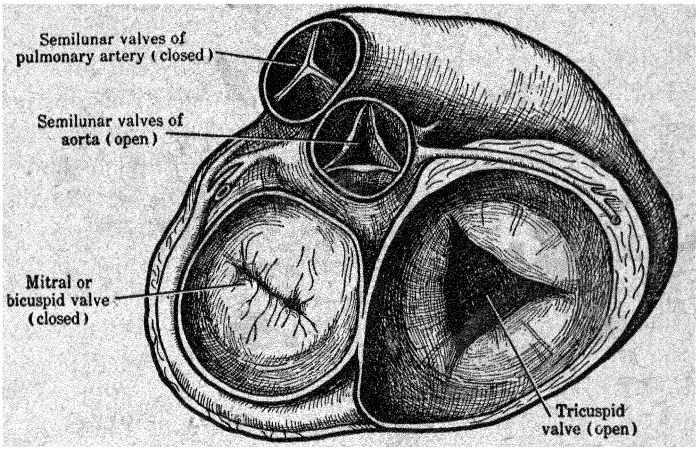


FIG. 73. Action of the valves of the heart. *Redrawn from Haggard, "The Science of Health and Disease." By permission of the publishers, Harper and Brothers.*

luna—moon) which prevent the backward flow of blood into the heart.

The blood has now reached the lungs, where it loses carbon dioxide and receives oxygen. The **oxygenated blood** returns from the lungs to the left auricle through the **pulmonary veins.** When the left auricle contracts, the blood flows into the left ventricle through the opening between the left auricle and left ventricle over the **bicuspid or mitral valve.** When the left ventricle contracts, the mitral valve prevents the flow back into the auricle and the blood is forced into a large vessel, the **aorta** (Fig. 72). In the opening between the aorta and the left ventricle are three **semilunar valves** similar to those at the base of the pulmonary artery and functioning in the same manner.

Sometimes as a result of disease or other causes the valves fail to close properly and some of the blood pushes back into the chamber which it has just left. This is known as **leakage of the heart.** Thus when the left ventricle contracts leakage of the bicuspid valve allows blood to escape into the left auricle. Such

leakage may be caused by weakness in the valves or by growths on them which prevent proper closure.

From the aorta, arteries lead off to the neck and head, the arms, the alimentary tract—in fact to all the organs and structures of the body except the lungs. It has been estimated that, in pumping this blood through the body, the work done by the heart every 24 hours would be sufficient to raise a man weighing 150 pounds to a height 200 feet above the top of the Empire State Building in New York City.

If the heart exerts so great a pressure, then the walls of the vessels through which the blood flows must also be under constant pressure, those of the arteries nearest the heart being under the greatest pressure. Consequently the walls of the arteries are much thicker than those of the veins (Fig. 71). The walls of both the arteries and veins have the same structural plan, but the arteries have more muscle and elastic tissue. This is particularly true of the aorta. After the blood passes through the capillaries and gets into the veins, there is a steady flow toward the heart but not nearly so strong as the flow from the arteries. The veins contain small valves that prevent any backward flow of the blood (Fig. 71).

The first rush of blood from the heart distends the walls of the aorta and larger arteries, which maintain this pressure through the contracting muscles and the elastic tissue. This mechanism makes possible a constant pressure which forces the blood to all parts of the body and through the small vessels where the resistance becomes increasingly greater.

Blood pressure is measured by placing around the arm an air-tight rubber cuff into which air is pumped until the pressure causes the collapse of the main artery of the arm. This obliterates the pulse at the wrist. The pressure, measured in milligrams of mercury, is recorded by a gauge. It is the **systolic pressure** or the pressure at the time of the contraction of the heart. Usually "no definite cause can be found for low blood pressure" though it is present in certain chronic diseases. High blood pressure may be the result of overweight, improper diet, infections, age, or the rush and worry of modern life. It may be caused by hardening of the arteries **(arteriosclerosis).**

There are in reality four transportation systems in the human body and in the body of most of the higher animals: the **systemic system,** which carries the blood to the limbs, brain, the organs of digestion, and other parts of the body; a **pulmonary system,** which carries the blood from the right side of the heart to the lungs and returns it to the left side of the heart; and a system called the **hepatic portal system,** which drains the blood from the intestines and carries

the digested proteins and carbohydrates through the portal vein to the liver, where, as we have seen, carbohydrates are stored (Fig. 70). The **lymphatic system** will be discussed later. In some of the backboned animals like fishes and frogs the **renal portal system** (*renes*—kidney; *portare*—to carry) carries the venous blood from the tail regions to the kidneys.

THE CIRCULATING MEDIUM

The circulating medium or blood is a very complex liquid tissue, much more complex than the average person realizes. In some of the lower animals the blood is almost transparent and much simpler in composition than the blood of the higher forms. In man and the higher vertebrates about 50–60 per cent of the blood is made up of a liquid called the **plasma.** The remaining 50–40 per cent of the blood volume consists of millions of **red** and **white corpuscles** and floating **blood platelets.**

Plasma. The plasma, the liquid part of the blood, is approximately 90 per cent water. Dissolved in the plasma and distributed by it is a great variety of substances. Practically every soluble substance found in any part of the body is also found in the blood in variable amounts on its way to or from the various organs and tissues. The plasma is the medium for the distribution of food, hormones, enzymes, antibodies, and metabolic wastes like carbon dioxide and urea. Glucose is always found in the plasma and is maintained at a concentration of about 0.1 per cent. A reduction in glucose to a concentration of 0.04 per cent or less may result in convulsions, unconsciousness, and death. Seven to nine per cent by weight of the plasma is made up of the plasma proteins. They play an important role in maintaining blood pressure and water balance between the blood and the tissue fluid. One of the proteins, fibrinogen, is necessary in the clotting of the blood. In recent years the physical chemists have developed methods for separating the various proteins of the plasma.

The most useful of the plasma proteins from a therapeutic viewpoint are albumin, gamma globulin, and fibrinogen. The albumin molecules appear to be well suited for the maintenance of blood volume in a person suffering from hemorrhage and shock since they readily bring the water by osmosis from the surrounding tissues to the blood stream and thus raise the blood pressure. Certain of the gamma globulins contain antibodies, a fact shown to be especially true in measles. Fibrinogen has been processed into fibrin foam and

fibrin film (Fig. 74). The sponge-like fibrin foam is used to control excess bleeding in operations, especially those on the brain. Fibrin

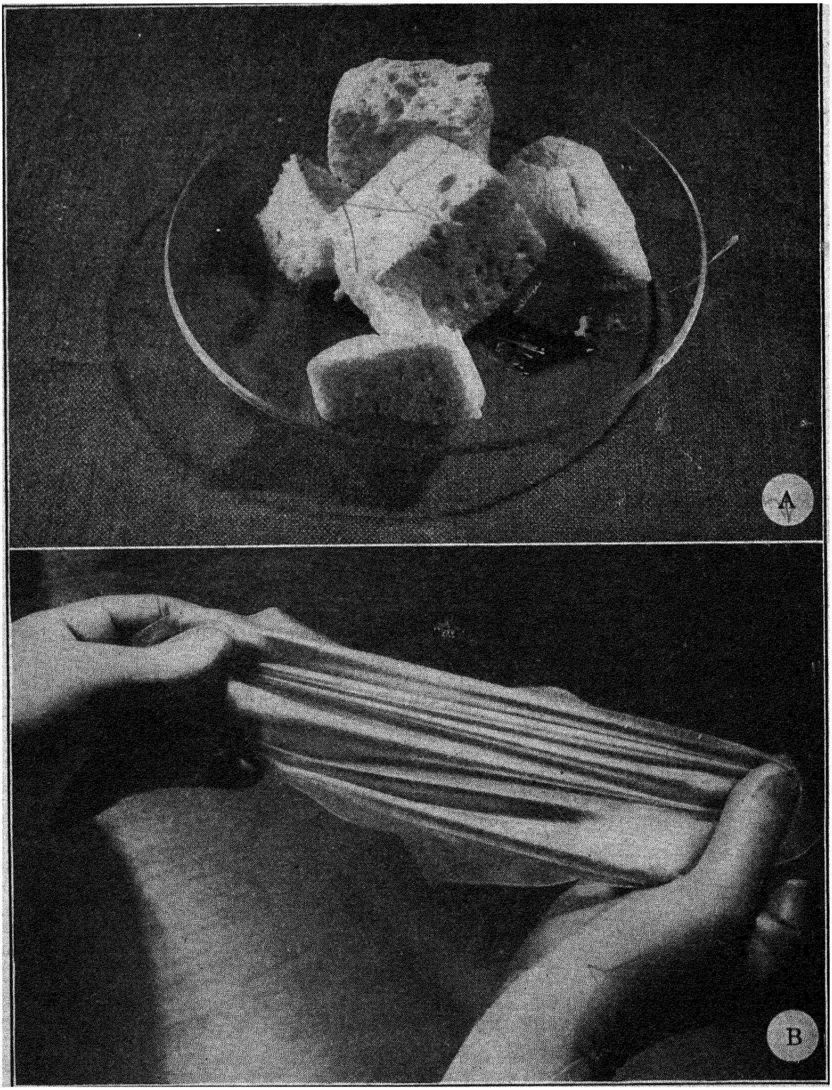


FIG. 74. Plasma proteins: *A*, plasma foam; *B*, plasma sheet. *Photographs by Fritz Goro; by permission of Life Publishing Co.*

film has been cut and fitted into place to repair injuries to the covering of the brain. Fibrinogen with thrombin has been found useful for cementing skin grafts in place.

Blood banks. Almost everyone has heard of blood banks, where "dried" blood is stored which can be given later by transfusions to those in need of it. Such "dried" blood is really only the dried blood serum. Blood is drawn from an individual, and the red and white corpuscles are separated from the serum by centrifuging. The serum is frozen, and the frozen chunks are evaporated, leaving the dried, flaky, yellow-brown plasma, which contains glucose, proteins, and certain other substances of the plasma. For emergency transfusions this dried material is mixed with triple-distilled sterilized water. The Red Cross worker, the surgeon, and the nurse on the battlefield of World War II were equipped with kits containing the materials necessary for making transfusions, and thousands of lives were saved by this means. On the first day after Pearl Harbor, 750 pints of plasma were used. Usually, the transfusion of dried blood is followed by a regular transfusion as soon as possible. Serum transfusions have been found to be especially effective in victims of severe burns and after poison-gas attacks.

Red corpuscles. The red color of the blood is caused by the presence of countless, flattened, biconcave, disklike cells called **red corpuscles (erythrocytes)** (*erythros*—red; *cytos*), which contain a red pigment called **hemoglobin.** In man there are about 5,000,000 in a cubic millimeter of blood (Fig. 75). They are formed in the **red marrow** of the long bones of the body, in some of the flat bones like the ribs, and in some of the bones of the skull. In man these red corpuscles in their later stages have no nuclei. Red blood corpuscles differ in various animals. For instance, those of the frog are oval, nucleated, and biconvex.

Hemoglobin, an iron-containing pigment combined with a protein, enters into a loose combination with oxygen and in this way carries oxygen to the various cells of the body. When the red corpuscles reach places in the organism where the oxygen content is low, the oxygen diffuses from the hemoglobin and passes to these regions of low oxygen concentration. Arterial blood, owing to the large amount of oxygen carried, has a bright red color; venous blood, because of reduced oxygen content, is dark red. The life of a red corpuscle is about 30–40 days. The worn-out or injured cells are destroyed in the liver and spleen. The iron is returned to the bone marrow, and the hematin fragment of the hemoglobin changes into bile pigment.

White corpuscles. These are small, nucleated, semitranslucent cells, numbering about 8,000 per cubic millimeter. There are a number of different types of white corpuscles, but we shall discuss only the two most numerous, the **leucocytes** and the **lymphocytes** (Figs. 75 and 76). The leucocytes are capable of changing their shape and moving or migrating independently through the intercellular spaces among the tissues by ameboid movement, so called because

it resembles the movement of the ameba. The number of these cells depends upon the condition of the body. In infection they generally increase rapidly in number, but in typhoid and malaria their number is reduced. Leucocytes are scavengers, or perhaps we might say "soldiers." When bacteria invade any part of the body, the leuco-

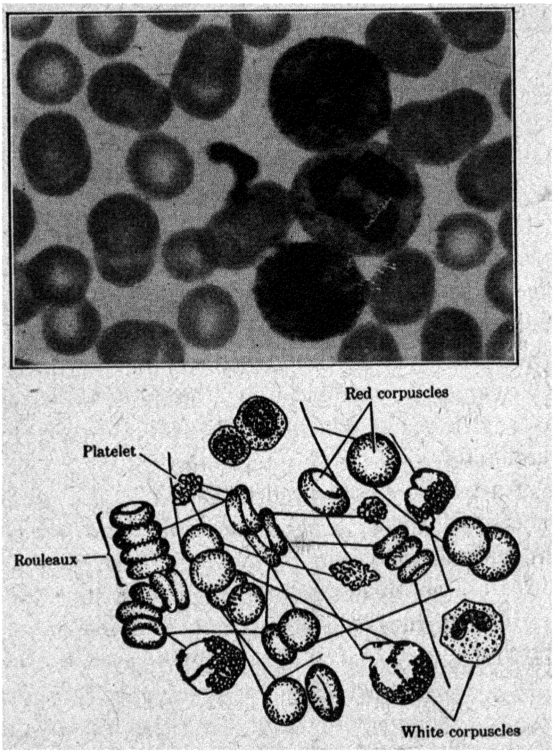


FIG. 75. Blood cells. *Above,* photomicrograph of red corpuscles and three large white corpuscles. *By permission of the General Biological Supply House.*

cytes gather there in great numbers and attack and feed on the bacteria and broken-down tissues by engulfing the particles. This process is called **phagocytosis** (*phagein*—to eat; *cytos*), hence the leucocytes are often known as **phagocytes.** Some of the leucocytes may be destroyed by bacterial acid. Thus there may result at the focus of the infection an accumulation of blood, tissue fluid, dead and living bacteria, leucocytes, and disintegrating cells. This entire yellowish or whitish mass is known as pus. The lymphocytes are smaller than the leucocytes and contain relatively little cytoplasm. They are useful in healing wounds and in replacing broken and torn tissues by transformation into connective-tissue cells.

Blood counts. We have already pointed out that the number of red corpuscles, leucocytes, and lymphocytes is fairly constant under normal conditions for certain specified comparable amounts of blood. In making a blood count a measured amount of blood is drawn and accurately diluted 200 times. A measured amount is spread upon a counting chamber, and the cells are counted under the microscope. The amount per cubic millimeter is then determined. Sometimes the amount of hemoglobin present is estimated by comparing the color of a sample with color charts. By either one or both of these methods the physician diagnoses a case of **anemia** if the red count is low or if the amount of hemoglobin is low. Anemia results in deficient oxygen supply, loss of energy, and general bodily impairment.

Blood platelets. These are small, roughly disk-shaped, granular bodies which aid in the clotting of blood. They probably have the same origin as the red blood corpuscles.

Clotting or coagulation. If blood is allowed to stand in a test tube or remain on the surface of a wound, it soon forms a jellylike mass or clot which gradually contracts, squeezing out a yellowish liquid, the **blood serum.** This very commonplace biological process, which is so frequently seen, in reality is very complex and involves a chain of events. It serves to illustrate how complicated many of the life processes are. Although certain details of blood clotting are not yet definitely understood, the main steps may be described as follows: As a result of a wound the injured tissue cells and the disintegrating blood platelets may release a substance called **thrombokinase.** This in turn acts with the calcium in the blood and another substance, **prothrombin,** to form **thrombin.** Thrombin in its turn acts on another substance, **fibrinogen** (fibrin; *genes*—born of), to change it into the **fibrin** which forms an interlacing network of strands, enmeshed in which are numerous red corpuscles. Fibrin is absolutely necessary for the clotting but does not occur as such in the blood stream. Summarized, this process probably is as follows:

Disintegrating platelets and injured tissue cells → Thrombokinase
Thrombokinase + Prothrombin + Calcium → Thrombin
Thrombin + Fibrinogen → Fibrin
Fibrin and red corpuscles → Clot

In certain diseases the blood loses its clotting power. Also, some unfortunate individuals, called "bleeders," have blood which clots slowly, and often an ordinary wound results in a severe hemorrhage. This condition is hereditary. Clendening reported the case of a butcher's delivery boy who, because of the jars received in jumping down from the wagon, started so many hemorrhages in his joints that he was crippled for life.

Sometimes as a result of injury or disease a clot, known as a **thrombus,** may form in a blood vessel. This clot may shut off the normal supply of blood to an organ or tissue. If it occurs in the heart it may result in death. A thrombus in the legs may cause varicose veins, and in the rectum, it may cause hemorrhoids. Occasionally, part of the thrombus breaks off and is carried free in the circulation; it is known as an **embolus** and, if it lodges in the blood vessels of the brain or the heart, may cause death.

Lymph. The blood pressure in the capillaries causes some of the liquid plasma, minus plasma proteins, to be forced out into the intercellular spaces. This watery liquid fills the intercellular spaces and bathes some part of practically every individual cell of the organism. Someone has aptly said that almost every cell has its own "water front." The intercellular lymph, called **tissue fluid,** and the plasma within the capillaries, form an almost continuous liquid system (Fig. 76). Dissolved materials diffuse from the plasma of the blood into the tissue fluid and thus are accessible to the individual cells. Waste materials are given off by the cells into the tissue fluid, which may diffuse back into the blood stream by way of the venous capillaries or the lymph vessels. The lymphatic system extends throughout the entire body. The main lymph vessels resemble the veins in structure. They have valves but are thinner walled (Fig. 71). The composition of lymph is very much like that of the blood plasma minus the red corpuscles and certain proteins. The movement of the lymph toward the heart is caused by muscular contraction, particularly in the arms and legs, as well as by breathing movements. In some lower animals there may be pulsating "lymph hearts" which assist in keeping the lymph in circulation. The valves of the lymph vessels aid in keeping the lymph flowing toward the heart. At various places along the lymph tubes are rounded swellings called **lymph nodes** (Fig. 77), which aid not only in straining out bacteria and certain foreign particles but also in producing new lymphocytes. The lymph nodes of the lungs of city dwellers often become very dark from the accumulation of soot and dust particles. The "strained-out" bacteria are phagocytized by the leucocytes present in the lymph nodes. Often there is such an accumulation of bacteria and leucocytes in the lymph nodes near the site of an infection that they become swollen ("swollen glands") and sore to the touch.

The spleen. This organ of the vascular system seems to have at least three important functions. It acts as a reservoir for blood in which there is a higher concentration of red corpuscles. In an emergency, such as a rise in environmental temperature, hemorrhage, or emotional excitement, the spleen contracts, throwing reserve blood

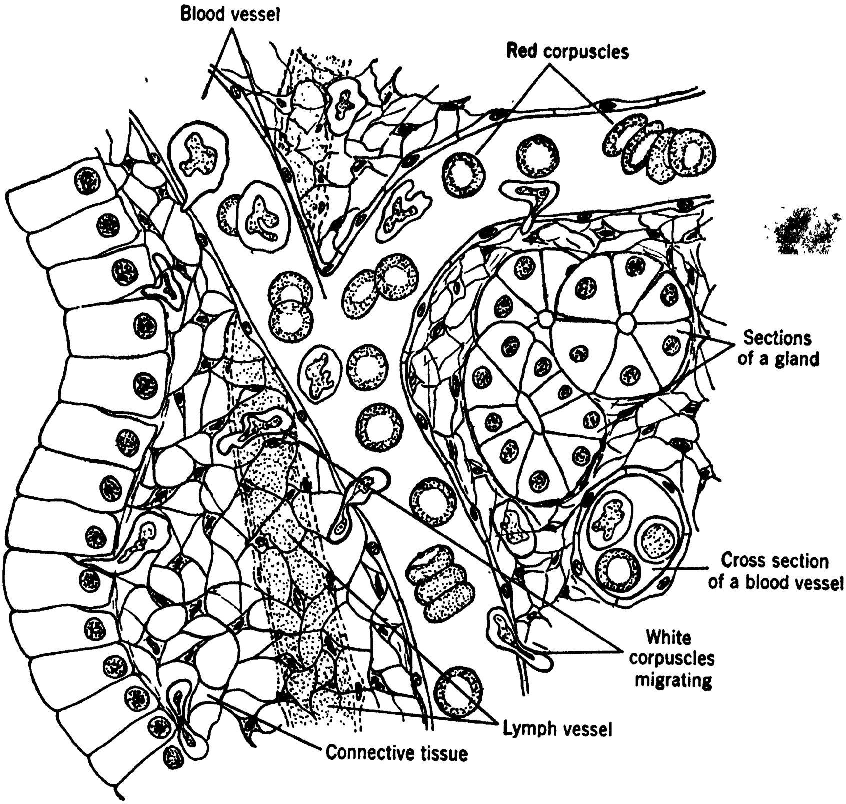


FIG. 76. Diagram showing relation of blood cells, plasma (yellow), and tissue fluid (yellow) to the cells of other tissues.

and corpuscles into the circulation. In the spleen, old and unhealthy red corpuscles are probably eliminated by the action of leucocytes. Finally, the spleen may manufacture lymphocytes.

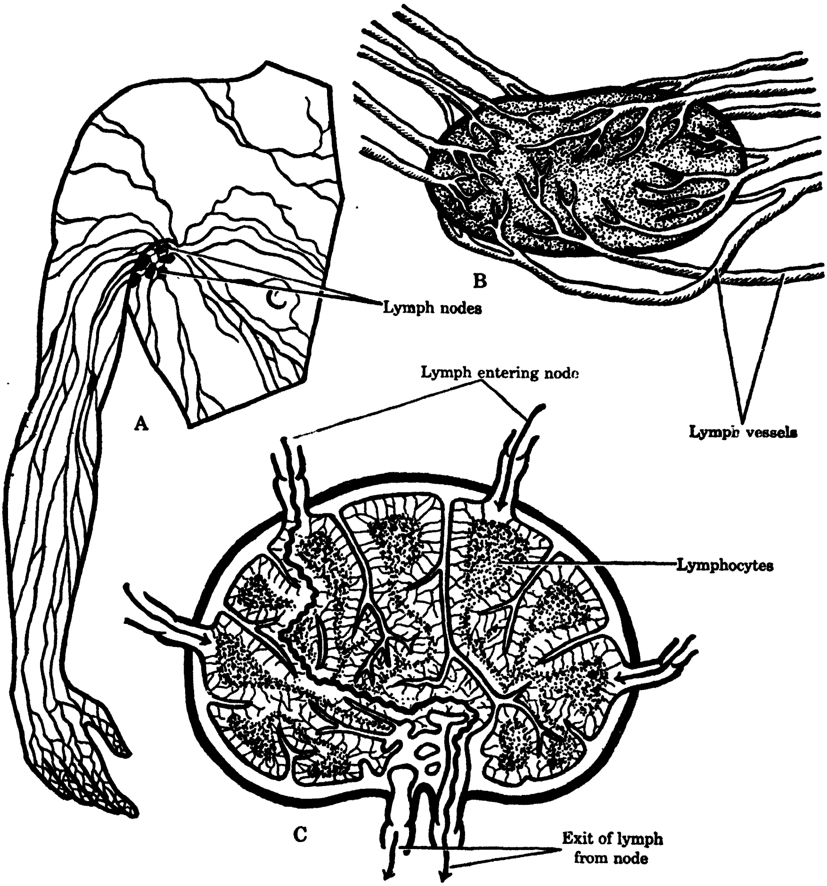


FIG. 77. *A,* lymph, lymph vessels, and lymph nodes of the arm. *B,* diagram of lymph vessels entering and leaving lymph gland. *C,* diagram of lymph node. The lymph flows slowly through the node (note arrows) by labyrinthine blood passages, and solid particles are filtered from the lymph and engulfed by white corpuscles (not shown). *A and C redrawn from Carlson and Johnson, "The Machinery of the Body." By permission of the authors and the University of Chicago Press.*

THE CIRCULATORY SYSTEMS OF OTHER ANIMALS

When the walls of blood vessels in certain regions develop additional muscle fibers and have the power of rhythmic pulsation, they

are known as **hearts.** Thus in the earthworm there are five pairs of specialized arches around the esophagus which aid, to some extent, the dorsal blood vessel in pumping the blood through the animal. The heart of an insect is a single muscular tube extending along the back, but it is actually only a specialized blood vessel which may be said to correspond to a ventricle (Fig. 78). The blood collects in a space or sinus around this tube or heart and enters through little openings, called **ostia** (*ostium*—entrance), which are provided with valves that close when the heart contracts. The clam has a heart made up of one ventricle and two auricles (Figs. 78 and 79). It pumps only oxygenated blood, since the blood comes to the auricles

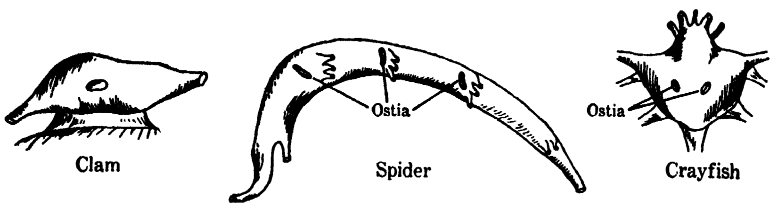


FIG. 78. Hearts of three different invertebrate animals.

from the gills and mantle where it has lost carbon dioxide and gained oxygen.

The animals just mentioned, like almost all the non-backboned, multicellular animals, have a more or less well-developed system of arteries and veins. In addition there are numerous spaces among the tissues and organs through which the blood flows. This type of circulation in which the blood is not confined entirely to vessels is known as an **open circulation** (Fig. 79).

There are a number of variations in the heart and blood vessels of the backboned animals. Almost all the vertebrates have a **closed circulation,** although the lymphatic system might be considered comparable to the open circulation of lower forms. The heart of fishes has one auricle and one ventricle. It contains only venous blood, which is pumped to the gills through **afferent branchial arteries** (*adfero*—I carry toward; *branchus*—gill) where it is oxygenated and then transported to the aorta by the **efferent branchial arteries** (*effero*—I carry away from). This is a **branchial** or **gill circulation** instead of a pulmonary or lung circulation (Fig. 79).

With the development of lungs as a breathing device, new structural modifications and shifts appear in the heart and blood vessels to prevent the mixing of the arterial with the venous blood. In the amphibians (frogs, toads, water dogs, newts, and others) the heart

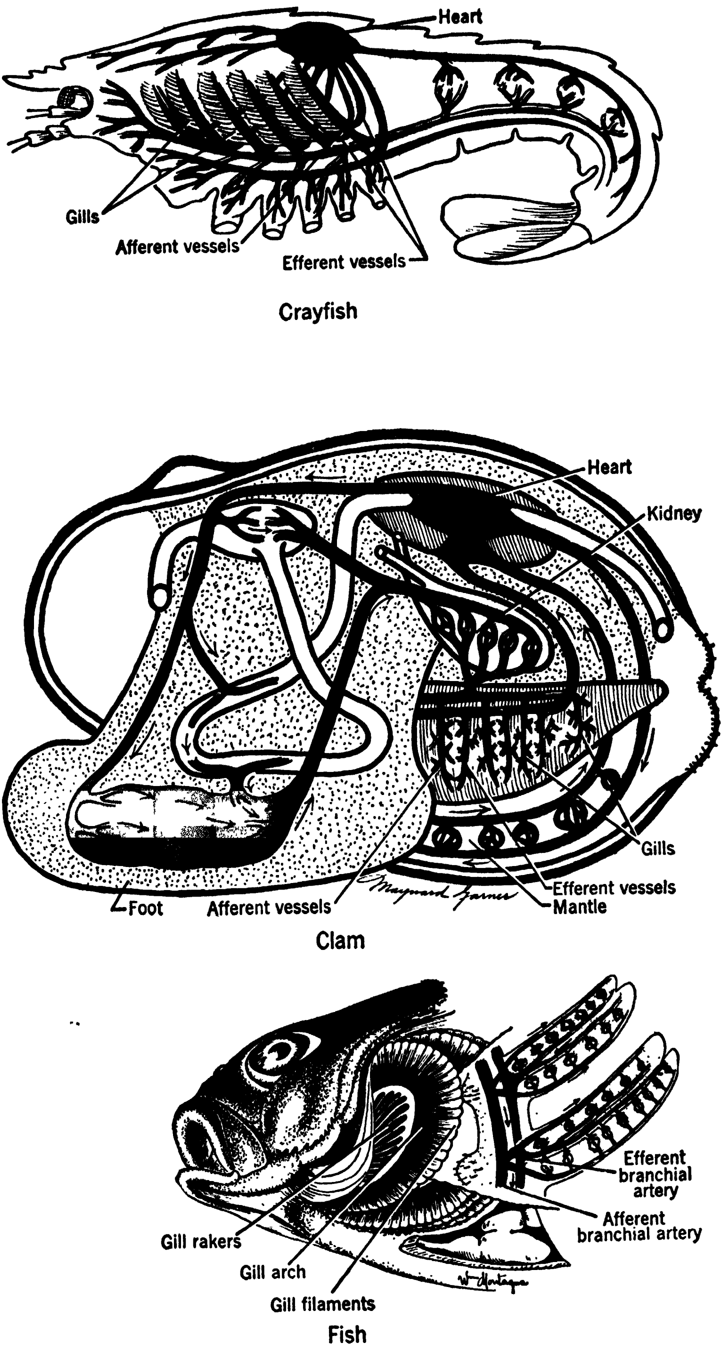


Fig. 79. Diagrams showing the circulation and oxygenation of the blood in certain aquatic animals.

is made up of a single ventricle and a right and a left auricle separated by a wall, or **septum** (Fig. 80). However, a special valvular mechanism is present which assists in preventing any great mixture of the arterial and venous blood. In reptiles, birds, and mammals a wall or septum is present which divides the ventricle into right and left ventricles. This ventricular septum is complete in birds and mammals but is incomplete in most of the reptiles. With complete

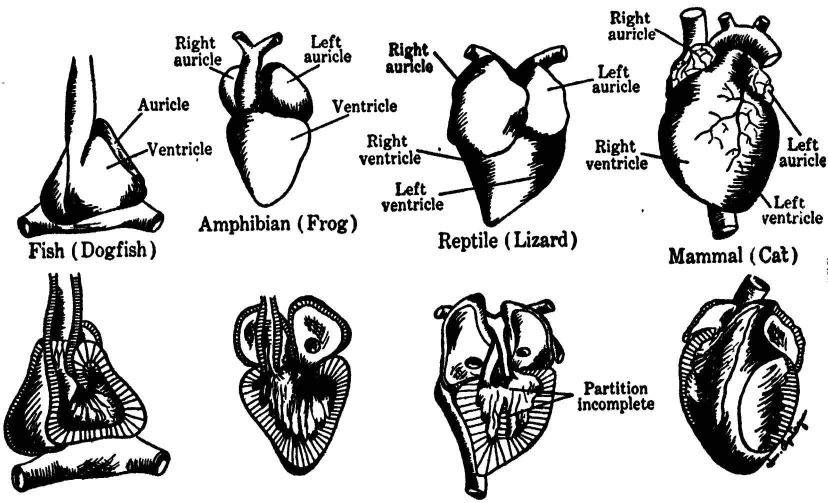


FIG. 80. Comparative study of different forms of vertebrate hearts. Note progressive development in the number of auricles and ventricles and the complete separation of the chambers on the right side of the heart from those on the left, thus preventing a mixture of the venous blood and arterial blood.

septa in both auricles and ventricles there is no mixing of arterial and venous blood. Study carefully the semidiagrammatic sketches in Fig. 80.

THE BLOOD AND BODY DEFENSE—IMMUNITY

Organisms may suffer from two types of disease, **non-infectious** and **infectious.** We have already discussed the cause and cure for certain non-infectious diseases of man, such as pellagra, beriberi, and xerophthalmia. These diseases are not communicable. Mumps, scarlet fever, measles, typhoid fever, tuberculosis, and diphtheria are diseases which practically everyone knows are communicable from one individual to another, or infectious. Diseases in either category afflict both animals and plants.

The organism has certain natural defenses against the invasion of bacteria and other parasitic organisms, all of which are protein in nature since they are made of protoplasm. Organisms likewise are able to combat bacterial products **(toxins)** and proteins foreign to the organism. The three groups of substances—bacteria, bacterial products, and foreign proteins—are known as **antigens** (*anti*—against; *genes*—born of). When an antigen enters the tissue of an organism, the tissues of the organism secrete a specific substance, known as an **antibody,** which in some way combines with the antigen, and nullifies its harmful effects. We know how antibodies act, and, although we do not know in what tissues they are synthesized or their chemical formulas, it is certain that the blood serum contains these antibodies.

There are five general types of antibodies: **lysins** (*lysis*—loosening), which destroy the cell walls of foreign cells and cause dispersion of their protoplasms; **opsonins** (*opsonion*—sauce), which cause the leucocytes to engulf more bacteria; **agglutinins** (*agglutinans*—gluing), which cause bacterial cells to clump together; **precipitins,** which aggregate the molecules of a protein with formation of a precipitate; and **antitoxins** (*anti*—against; *toxin*—poison), which neutralize the poisons given off by some organisms, such as bacteria. The first three groups of antibodies attack bacteria or entire cells, whereas the last group mentioned neutralizes bacterial products or toxic substances. Since these reactions increase specific resistance to disease-producing agents, or produce immunity, they are called immunological reactions, and all such reactions are highly specific. A typhoid bacterium, an antigen, can be detected by an antigen-antibody reaction; for example, an immune animal's serum may be diluted many thousand fold and yet cause agglutination of typhoid cells, whereas a non-immune animal might not show this reaction after a hundred-fold dilution of its serum.

Cytolysins (*cytos*—cell; *lysis*—loosening). When foreign tissues, such as red corpuscles or living or dead bacteria, are injected into the blood stream, protective substances called lysins are formed which will dissolve (lytic action) the walls of the foreign cells and break up the cells. For example, if the serum of a rabbit which has had human red corpuscles previously injected into its blood is added to a mixture of human and rabbit blood in a test tube, the human corpuscles will be dissolved but no others will be affected. Thus we see that cytolysins are specific in their reactions.

This knowledge concerning lytic action is utilized in inoculations against typhoid fever, smallpox, and other diseases. Dead typhoid

germs are injected into the animal intramuscularly, causing the formation of a specific cytolysin. Later, if live typhoid germs invade the body, they will be destroyed by the cytolysin present. The lytic reaction is also the basis of the Wassermann blood test for syphilis as well as for other diagnostic tests.

Opsonins. Wright discovered that the leucocytes could not take up the bacteria unless they had first been acted upon by serum. The blood serum from immune animals "prepared" bacteria or "made them more appetizing" than did the serum of normal blood. This

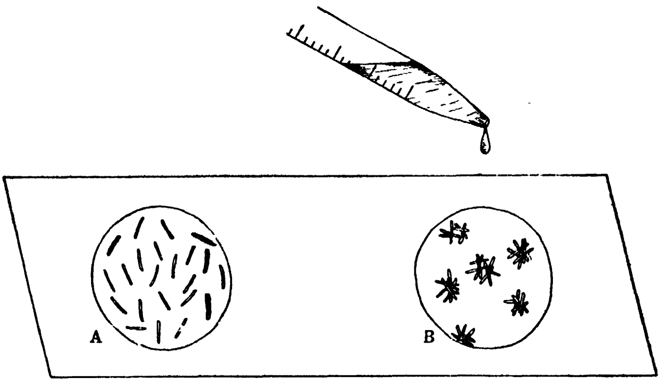


FIG. 81. Diagram showing agglutinating of bacteria. *A*, uniform distribution of bacteria within a droplet of culture. *B*, clumping of bacteria after the addition of blood serum containing agglutinin.

seemed to indicate the presence of something in the blood serum which caused the white corpuscles to engulf more bacteria, hence the name opsonin. Increased production of these opsonins can be stimulated by injections of various kinds of dead or living bacteria into the blood stream.

Agglutinins and precipitins. These two kinds of substances are so similar in their action that they may properly be grouped as the same type of antibody. Agglutinins cause bacteria or foreign cells to clump together; precipitins act on smaller units, such as molecules. Both reactions tend to localize the foreign protein and render it more available to the phagocytes.

Agglutinins are specific in their reactions and are used for laboratory diagnosis of disease. Thus, in the Widal test for typhoid fever, blood serum from the suspected patient, if added to a culture of known typhoid bacteria, will cause the bacteria to clump or agglutinate (Fig. 81). Clearly, this would not happen if the patient had some other disease. Types I, II, and III of pneumonia may be diagnosed by the same general method.

Precipitins can be readily built up in the blood by repeated injections of some specific foreign protein. To illustrate, if chicken serum is repeatedly injected into the circulation of a rabbit, a precipitin is formed. Now if some blood serum from the injected rabbit is added to some chicken serum, a visible precipitate is formed. Not

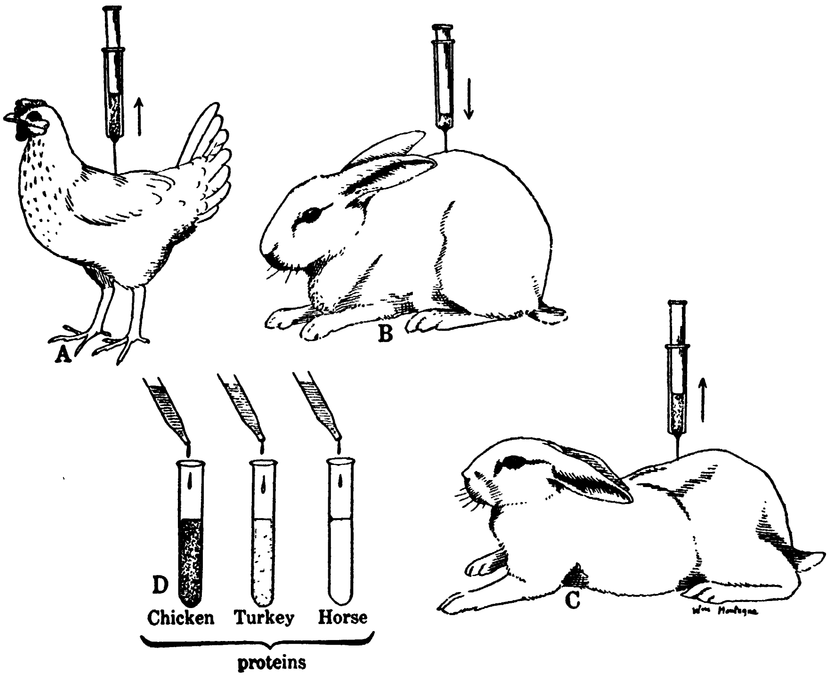


FIG. 82. Diagram showing preparation and reaction of precipitins. *A*, withdrawing serum (protein) from a chicken. *B*, injecting chicken protein into a rabbit. *C*, withdrawing serum from the rabbit after an interval of several days. *D*, result of adding this serum to different proteins. Note the dense precipitate when mixed with chicken protein, a slighter reaction with turkey protein (an animal closely related to the chicken), and no reaction with horse protein.

only chicken serum but also serum of animals closely related to the chicken will be precipitated in this way. The closer the relationship, the more marked is this precipitating reaction (Fig. 82). Therefore this method can be used to detect animal relationships. Precipitins are fairly specific in their reactions. For example, if cow's milk is injected into the rabbit's blood stream there will be produced a precipitin which will precipitate the casein of the milk. The precipitin reaction has been made use of in medicolegal cases to determine whether or not a stain was made by human blood.

Antitoxins. Some disease germs or bacteria, such as those causing diphtheria, owe their deadliness to the toxins or poisons which they throw off into the blood stream as a result of their metabolism. Diphtheria toxin produces characteristic effects upon heart muscle; tetanus toxin causes marked changes in the central nervous system. To counteract or neutralize the effects of these toxins, the living cells of the infected animal form chemical substances called **antitoxins.** Antitoxins unite with the toxins in some as yet unexplained way and counteract their poisonous properties. Antitoxins are specific in their reactions, and consequently each toxin must be met with a specific antitoxin.

In former years, if a person contracted diphtheria, his recovery depended upon whether or not he could form a sufficient amount of antitoxin. Today, diphtheria antitoxins are prepared commercially from horses. The horse is an excellent animal for the production of large quantities of the antitoxin, and builds up antitoxins when injected with the toxin of diphtheria. The serum is then extracted and prepared for the market. Today, thanks to the bacteriologist and the horse, "no child need have diphtheria."

Cobra and rattlesnake venoms are now combated by means of venom antitoxins. The venom is extracted from the snakes, and the antitoxin is built up in the goat in much the same way as in horses. Both bacterial antitoxins and antivenins are now available commercially. Further discussion of bacteria will be presented later.

Originally, it was thought that for each specific immunological reaction there had to be present a specific antibody and therefore there had to be many separate, distinct, and independent antibodies. Extensive investigation has added to the knowledge concerning these reactions, and it is now thought that the essential factor common to all manifestations of the union of antigen and antibody, i.e., clumping of cells, formation of precipitates, or lysis of cells, regardless of these ways in which the union can be detected, are caused by the same antibody. This interpretation has been termed by some workers the "unitarian" hypothesis. In all reactions showing the union of antigen and antibody, the antigen must not have been altered chemically and certain environmental conditions—salt content, temperature, hydrogen-ion concentration, etc.—must be present before the maximum reaction takes place.

Immunity. It has often been observed that some people when exposed to certain infectious diseases never become afflicted with them. They are said to be immune. The organisms, for this applies to other animals besides man, may have in their blood stream and tissue certain antibodies which counteract specific antigens. Thus

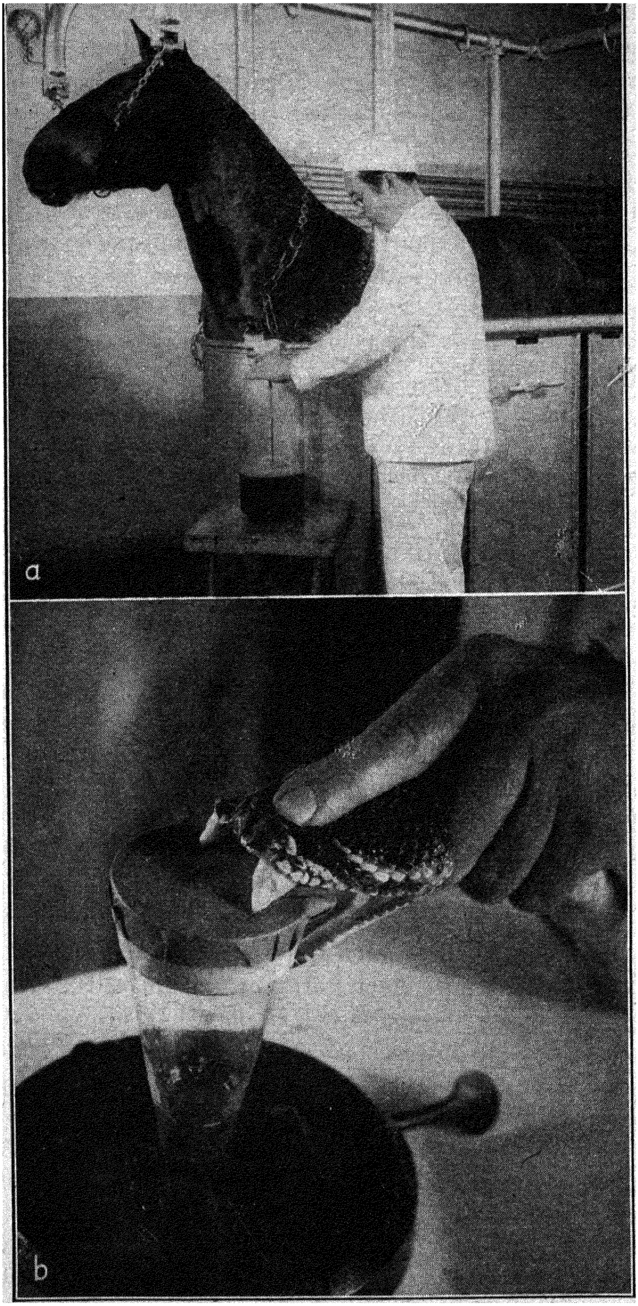


Plate I. Photographs showing (*a*) withdrawing anti-toxin from a horse; (*b*) extracting venom from a rattlesnake. (*a*) *By permission of Parke, Davis & Co.;* (*b*) *by permission of Sharpe & Dohme.*

the horse is naturally immune to diphtheria; the negro is more resistant to yellow fever than the white man; man is immune to distemper, a disease of dogs. This resistance is often called **natural immunity** or one phase of **active immunity.**

Man may acquire active immunity in several ways. He may have built up antibodies by having had certain diseases, or by having been protected against them by inoculation with dead bacteria as by typhoid "shots." This type of inoculation brings about reactions similar to those occasioned by living bacteria.

Again, man and certain organisms (particularly domestic cattle) may have a **passive immunity** which is effective over a period of years. In acquiring passive immunity, the antibodies built up in one animal are transferred to another animal. Immunity, in the last analysis, depends upon the amount and kind of antibodies in the blood serum, that is, the liquid part of the blood minus the fibrinogen or fibrin.

BLOOD GROUPS

It had been noticed by medical men that in blood transfusions the mixture of the two bloods in the patient often produced harmful instead of helpful results because of the agglutination of the red corpuscles of either the donor or the recipient or both. Death too frequently followed a transfusion. Landsteiner made a study of this condition and found that the action was no random process but that human blood could be classified into four main groups on the basis of the agglutinizing reaction. These four main groups have been designated as AB, A, B, and O, respectively. Incidentally it has since been found that there are subgroups also. The agglutinizing reaction takes place because of the presence of a specific **agglutinin** in the patient's blood which may act with another substance, **agglutinogen,** found in the erythrocytes of the donor. Today, many other factors such as the Rh factor, Hr factor, M factor, and N factor are known to exist, and consequently the story of these reactions has become quite complicated.

By simple tests it is possible to find out the type of blood a person has. Accordingly, before a transfusion is given the blood types of both patient and donor are ascertained. This is known as "matching bloods." A study of the accompanying chart will demonstrate the agglutinizing effects of the various types of blood (Fig. 83). Here it will be seen that any type of blood can be injected into a person with type AB. Likewise no serum will agglutinate erythrocytes of

group O, which can thus be used for transfusion into blood of any type. However, whenever possible, both donor and recipient should have the same type of blood.

These blood characteristics apparently are hereditary. However, they may not become fully established until sometime after infancy.

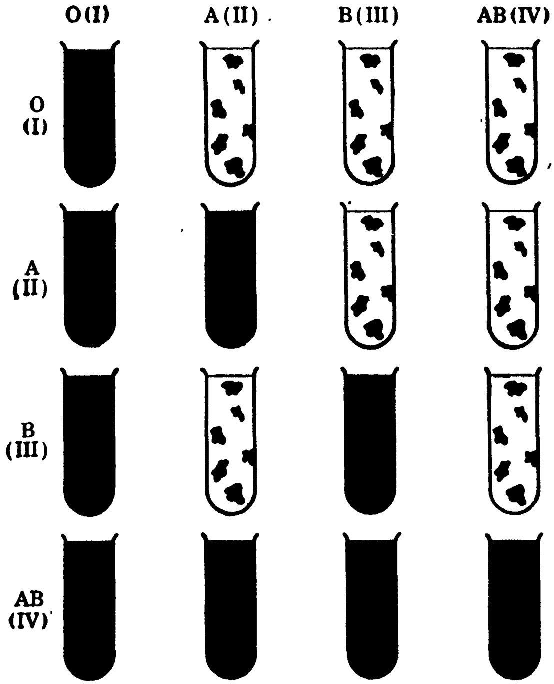


Fig. 83. Reactions of blood groups. Test tubes with solid black show no agglutination; all others show agglutination. *By permission from the film, "Brothers in Blood," Metro-Goldwyn-Mayer Pictures.*

A comparison of blood types has been used in court to determine the parentage of a child. Although paternity cannot be proved, yet the impossibility of being the father of the child in question may be established.

Blood groups have been detected in other animals besides man. Another interesting application of blood tests has been made by anthropologists in their study of races. By a special technique it has been possible to test mummified tissue. Tests have been made of Peruvian and Egyptian mummies as well as of certain Basket-maker Indians.

WILLIAM HARVEY AND THE DISCOVERY OF THE CIRCULATION OF THE BLOOD

The early Greek and Roman philosophers were greatly impressed with the various internal movements which they could see in themselves and others. They could feel the beating of the heart and of the pulse and recognized the fact that the body was filled with a red fluid which would flow from a wound. Most of their knowledge about these reactions came from talking about them and not through investigation. They could not examine human bodies because this was contrary to their religion and against their prejudices. They were content to examine the dead body only superficially. Galen considered the heart the source of the body's heat and thought the blood was a sort of oil which burned to furnish the required heat. In those days it was known that the blood in the right side of the heart was different from that in the left side of the heart, so Galen proposed the theory that the blood was "purified" by a passage through invisible pores in the wall or septum between the right and left ventricles. Another interesting idea held at that time was that the arteries contained air and the blood circulated in the veins. Gradually the theory gained ground that the heart propelled the blood. Servetus proved that the blood was oxygenated by the lungs and not by the passage through the interventricular wall. Eventually it was recognized that the heart did drive the blood through the pulmonary circulatory system, but the idea was held that the systemic circulation was accomplished in some other way.

William Harvey (1578–1657), an English physician, conceived the idea that the heart was responsible for the entire blood circulation and that the blood coursed, as it were, "in a circle." He was fascinated in watching the beating hearts of animals and at one time thought that "the motion of the heart was to be comprehended only by God." Continuing his experimentation, he showed that every time the heart contracted there was a pulse in the arteries, and that when the heart ceased to beat the pulse stopped. In this way he showed that the arteries contained blood coming directly from the heart. Later he was able to demonstrate that the flow of blood in the veins was toward the heart. In the course of his study of the arteries and veins, he showed that the valves in the veins would prevent the blood from going backward. He reasoned that, if an arm, for instance, were tightly bound or tied, if the blood were traveling from the heart

to the limbs, swelling of the veins would be on the side farthest from the heart, and the swelling of an artery would be nearest the heart. In this way the conclusion was reached that the arteries carried

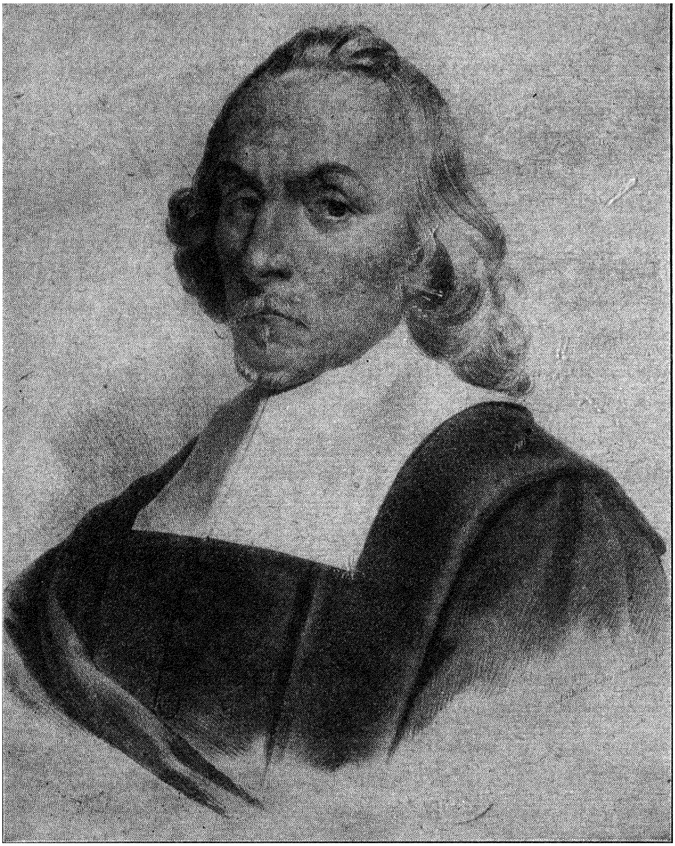


FIG. 84. William Harvey (1578–1657), discoverer of the circulation of the blood. *Photograph furnished by Army Medical Museum (negative No. 33740).*

blood away from the heart and that the veins carried it toward the heart.

The work of Harvey illustrates in a striking way the scientific method of approach. For nine years he continued experimental work on the circulation of various animals, and only after that did he publish his treatise on the circulation of the blood. The following statements from his book show this attitude very clearly. "I sought to discover the motions and uses of the heart from actual inspection

and not from the writings of others; at length, and by using greater and daily diligence and investigation, making frequent inspection of many and various animals, and collating numerous observations, I thought I had attained to the truth." When in doubt about publishing his findings, he made the following observation, which strikingly expresses the attitude of the scientist toward truth: "Doctrine once sown strikes deep its root, and reaped for antiquity influences all men. Still the die is cast, and my trust is in my love of truth and the candour of cultivated minds."

SUMMARY

From the foregoing it will readily be seen that the blood is a much more complex tissue than the average individual realizes. We have seen that it is responsible for the distribution of the digested food to the countless cells making up the organism. The blood likewise has a protective or immunizing function. Not only do some of its white corpuscles attack invading organisms but the blood stream itself carries antibodies that have been elaborated by the cells of the body. These protective substances are the various antitoxins, opsonins, and lysins. In addition to the functions just mentioned we shall see later that the blood is an important agency in the transportation of oxygen to the various tissues and in the collection and elimination of the waste products of metabolism and digestion. The blood plays an important part in regulating the temperature and water content of the organism.

CHAPTER VI

METABOLISM (*Continued*). HOW IS ENERGY RELEASED? RESPIRATION

We have been studying various processes that take place in living organisms such as food manufacture, synthesis of proteins and protoplasm, digestion, and distribution of nutritive materials. All these processes represent work of some sort, and we have already learned that work always involves a transfer or transformation of energy. In order that such work may be carried on there must be a continual supply of kinetic energy for those parts engaged in these various activities. We have seen how potential energy is stored in the cells, and we shall next learn how this energy is liberated in the working of the cells.

RESPIRATION IN PLANTS

The energy stored in the plant was originally obtained from the sun, but solar energy is not available during the hours of darkness, nor is it directly available to the deep-lying internal tissues of the plant. Since each living cell requires a constant supply of energy, obviously there must be some means by which an immediate supply of energy is made available in all living tissues at all times. The work of the cell then involves a transformation, into kinetic energy, of the potential energy stored up in its carbohydrates, fats, and proteins. This transformation is accomplished by a series of chemical reactions that break down these complex compounds into simpler forms, thereby releasing their energy content. In both plants and animals this liberation of energy, or transformation of potential into kinetic energy, is a fundamental and all-important metabolic process. In all organisms it is accomplished by similar chemical reactions, and the process is known as **respiration** (*respirare*—to breathe).

Nature of respiration. The process of respiration is sometimes compared to the burning of wood. When wood is burned we speak of the process as oxidation because the carbon in the wood combines with oxygen of the air, forming carbon dioxide. The hydrogen of the wood combines with oxygen to form water. In this process of

oxidation heat is liberated and light is emitted. In the process of respiration under ordinary conditions, oxygen is consumed, and organic compounds, such as carbohydrates and fats, are oxidized, forming water and carbon dioxide. Oxidation is an **exothermic** (*exo*—out of; *therme*—heat) reaction, and consequently *energy is always released* when substances are oxidized. This is the all-important role of respiration in the living organism, either plant or animal.

In certain plants and animals a portion of the energy released in respiration is not heat but a weak light called **bioluminescence** (*bios*—life; *lumen*—light). A familiar example is fox fire, often seen on decaying wood. The soft glow of light observed is a form of energy released by the respiration of fungi living in the wood. Perhaps respiration is so frequently thought of as a process of burning because the ultimate result—the production of carbon dioxide, water, and kinetic energy—is the same as that obtained from the burning of organic substances in air. Although this comparison may aid us in forming some simple conception of the nature of respiration, it can be relied upon only in the most superficial manner, for respiration in the cell is a very different process from the oxidation of coal in a furnace.

The oxidation of coal, as well as that of many other substances, takes place only at high temperatures; respiration in the plant takes place at ordinary temperatures, generally below 35° C. Likewise, respiration apparently occurs only in the protoplasm itself or in close proximity to it, which means that it occurs in the presence of water or in water, whereas combustion outside the living organism cannot be carried on in water. These differences between respiration and ordinary combustion of organic substances may be partly accounted for by the fact that the oxidation of organic compounds in respiration involves the action of oxidizing enzymes produced by the protoplasm. The enzymes concerned in or associated with respiration are: **oxidase, oxygenase, peroxidase, and catalase.**

The materials used and the waste products formed in respiration are clearly defined, but the reactions occurring in the cell by which the organic compounds are changed into wastes with release of energy are not so clearly understood. In other words, we know only the beginning and the end of the process and very little about the intermediate stages. The results of respiration can be comprehended more easily; e.g., stored foods are used up, and there is a consequent loss in dry weight. It has been demonstrated that one-fifth of the food material stored in the seeds is consumed in respiration to furnish the energy required for the development of sunflower seedlings ten days old. Respiration also produces heat, although it is much more evident in animals than in plants. If moist grain is stored in

a bin, respiration may generate sufficient heat to raise the temperature to the kindling point, giving rise to a conflagration that may destroy the entire building with its contents. Heavy losses are incurred as a result of such fires caused by spontaneous combustion originating in the chemical activity of respiration.

Influence of external factors. External conditions as well as enzymes tend to accelerate or retard respiratory activity. Respiration tends to increase with increase of temperature until the heat becomes injurious to the tissues. The amount of moisture present, within certain limits, also influences the rate or intensity of respiration. In corn (grain), respiration becomes pronounced when the moisture content exceeds 13 per cent; when the moisture content is raised to 15 per cent, the rate of respiration increases 400 per cent. Wounded parts have a higher respiratory rate than those that are intact, and young tissues have a much greater respiration intensity than old ones. The list of factors affecting respiration might be extended considerably, but these statements will suffice to show that respiration, like all other chemical processes, undergoes marked changes in response to the influence of various environmental conditions.

Aerobic and anaerobic respiration. Up to this point we have been considering respiration as it occurs when a normal supply of free oxygen is present. Such respiration is known as **aerobic respiration** (*aer*—air; *bios*—life). If a plant is placed in an atmosphere devoid of free oxygen, the process of respiration is greatly modified, various organic substances being formed as end products instead of carbon dioxide and water. Such respiration taking place in the absence of free oxygen is called **anaerobic respiration** or **fermentation** (*an*—without; *aer*). A common example is the fermentation of sugar by yeast, producing alcohol. In anaerobic respiration the oxidation of complex compounds is not entirely completed. Therefore, instead of carbon dioxide and water, such intermediate compounds as alcohol, acetic acid, formic acid, and lactic acid are formed. This partial oxidation of the organic compounds may be accompanied by a rearrangement of the atoms within the molecule without the presence of any oxygen, as in alcoholic fermentation, or it may involve the agency of oxygen derived from the breaking down of other compounds in the cell. The energy transformed into muscular contraction is released by anaerobic respiration, and some modern physiologists believe that within the living cell respiration occurs in two stages, the first being anaerobic and the second aerobic.

Respiration and photosynthesis. We have noted that in photosynthesis carbon dioxide is taken into the plant from the surrounding

atmosphere and oxygen is given off. In respiration this gaseous exchange is reversed. The failure to understand correctly that we are dealing here with two different processes has led to some erroneous conclusions. First, it is a rather common belief that plants are unlike animals because animals take up oxygen and give off carbon dioxide. Second, it is often said that it is a good practice to keep plants in the sleeping room because they give off oxygen. To avoid such confusion it is only necessary to recall the fact that all living cells must carry on respiration (oxidation processes) all the time to release the energy necessary for all vital activities, and in oxidation oxygen is taken up from the air and carbon dioxide is given off. All green plants, therefore, carry on respiratory activity all the time whereas photosynthesis can take place only during the hours of light; consequently at night a plant is giving off carbon dioxide instead of oxygen. An inspection of the parallel columns below will help to make clear the difference between the processes of photosynthesis and respiration.

Photosynthesis	Respiration
1. Occurs only in the chlorophyll-bearing cells of plants.	1. Occurs in every living plant and animal cell regardless of its color.
2. Occurs only in sunlight or under artificial illumination.	2. Occurs all the time—in darkness as well as in light.
3. Water and carbon dioxide are used in the process.	3. Water and carbon dioxide are end or waste products of the process.
4. Oxygen is given off as a waste product of the process.	4. Oxygen is used in the process.
5. Food is built up in the process.	5. Food is destroyed in the process.
6. Weight of the plant is increased.	6. Weight of the plant is decreased.
7. Energy is stored in the process.	7. Energy is released in the process.
8. The chemical equation is written: $6CO_2 + 6H_2O + \text{Energy} \rightarrow C_6H_{12}O_6 + 6O_2$	8. The chemical equation is written: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$

RESPIRATION IN ANIMALS

It has already been pointed out that all organisms, in order to live, must have a store of potential energy which is continuously being changed to kinetic energy. In animals this energy is released in the form of heat, movement, light, secretion, nerve-cell activity, and electricity. Further, every living cell of the organism must carry on these energy transformations. We now know the source of the animal's food supply. We have seen how the food is digested, absorbed, and transported to each individual cell by the blood. In

other words, the animal cells now have their store of potential energy, and the problem is to change it into kinetic energy. The transformation involves a supply of oxygen for each cell, to be used in respiration. The process of respiration, that is, the chemical and physical processes involved, is essentially the same for all protoplasm in either animals or plants. The main problem before us, then, is to see how animal cells receive their supply of oxygen and how the waste products of respiration are eliminated.

The breathing mechanism. In man, we find that air with 20 per cent of oxygen normally reaches the pharynx through the nose, where it passes over a system of much-folded, bony plates covered by a moist epithelium. At the back of the pharynx the air enters a slitlike opening called the **glottis,** which, in man, is guarded by a cartilaginous fold, the **epiglottis.** The glottis opens into a cartilaginous chamber, the **larynx** or voice box ("Adam's apple"), which contains the **vocal chords.** From the larynx a tubular trachea leads down through the neck, dividing in the chest region into the **right** and **left bronchi** (Fig. 85). A succession of small, incomplete rings of cartilage is present in both the trachea and the bronchi, supporting the walls of these tubes and rendering them non-collapsible. The right and left bronchi lead respectively to the right and left **lungs,** where they branch into an intricate system of tubes or **bronchioles** which finally end in tiny, thin-walled sacs called **alveoli.** The walls of the alveoli, bound together by connective tissue, contain countless permeating blood capillaries. Owing to the very large number of alveoli, the lungs have a spongy texture, and the surface exposed to the air is also very greatly increased. The total surface is estimated to be approximately 100 square yards. The lungs are located in the **thoracic cavity,** which is bounded laterally by the walls of the thorax supported by the curving ribs. This cavity is separated from the abdominal cavity by a broad sheet of muscular tissue, the **diaphragm.** The serous membrane lining the thoracic cavity and covering the lungs is called the **pleura.**

The mechanics of breathing. The thoracic cavity is an air-tight compartment enclosing the elastic lungs, which communicate with the outside only through the trachea. In normal breathing, as the chest cavity is enlarged, the pressure of the air in the lungs is reduced below atmospheric pressure and so air passes into the lungs. This is **inspiration** (*in*—into; *spirare*—to breathe). The enlargement of the chest cavity is brought about by the contracting of the **intercostal muscles** (*inter*—between; *costa*—rib), which moves the ribs upward and outward on each side and in front, and also by the

contracting of the muscular diaphragm, which increases the depth of the chest cavity (Fig. 86). Thus, in normal breathing, both the intercostal and diaphragm muscles function.

When the muscles involved in inspiration relax, the elastic recoil of the expanded lungs, aided by other factors, brings about a decrease

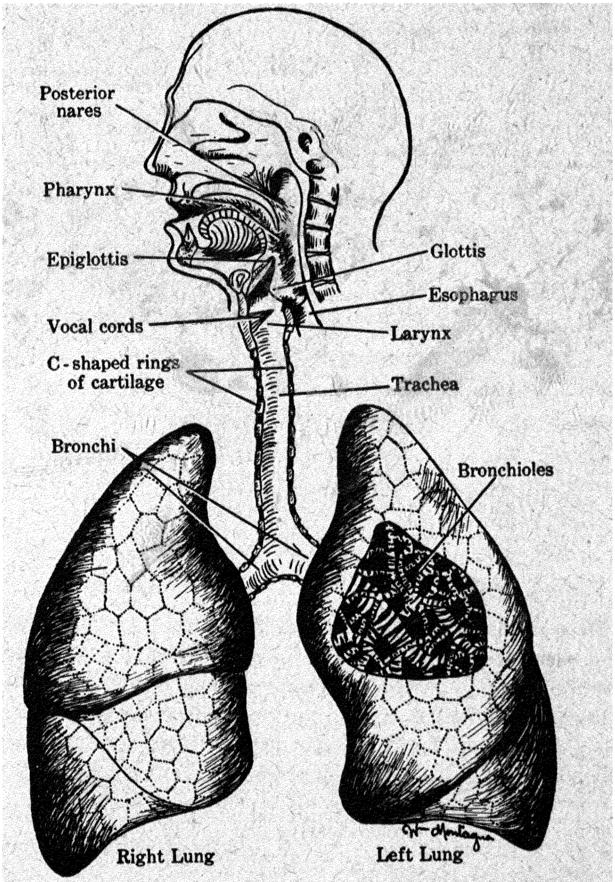


FIG. 85. The respiratory passages of man.

in the volume of the chest cavity and increases the pressure of the air in the lungs, causing some of it to be forced out (Fig. 86). This is **expiration** (*ex*—outside; *spirare*). In "forced" expiration, muscles of the abdominal wall and others are involved, effecting more rapid action and expulsion of a larger amount of air.

Exchanging oxygen and carbon dioxide. We have already seen that in diffusion the molecules of liquids, solids, or gases tend to

move from regions of high concentration to regions of lower concentration. According to the physical law of diffusion of gases, if a permeable membrane separates two volumes or two solutions of a gas at different pressures, the gas will pass through the membrane from a region of higher to one of lower pressure. Moreover, each

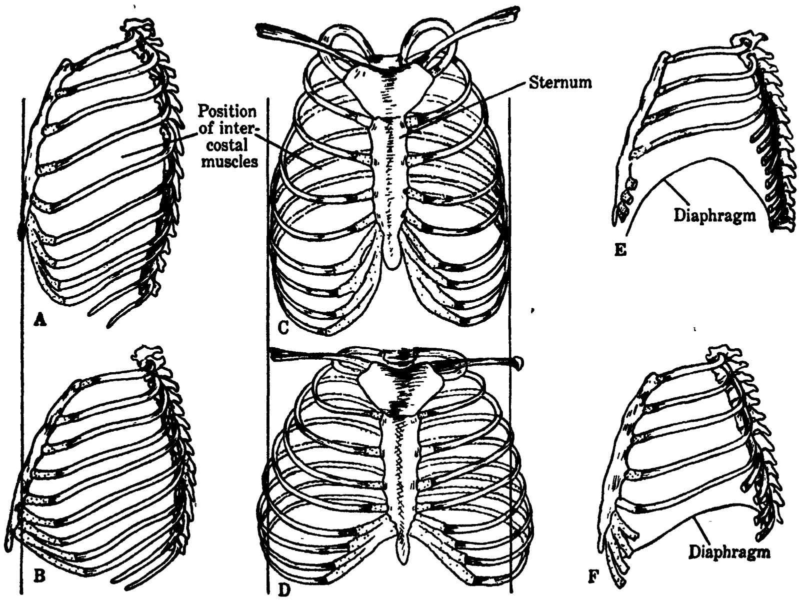


FIG. 86. Diagrams showing the mechanics of breathing. *A* and *C* show position of ribs and sternum at the end of an expiration. *B* and *D* show the ribs raised upward and outward by action of intercostal muscles. This causes an enlargement of the chest cavity, permitting air to rush into the lungs (inspiration). *E* and *F* show the role of the diaphragm in breathing. *E* shows the diaphragm raised, thus decreasing the volume of the chest cavity and aiding in expiration. *F* shows the diaphragm lowered (contracted), thus enlarging the chest cavity and aiding in inspiration.

gas behaves independently of any other gases that may be present. Now it has been shown that gases will pass through a *moist* membrane according to the principles just stated. The cell membrane is kept constantly moist by secretions from the protoplasm. So if "fresh" air containing oxygen comes into the alveoli of the lungs, and if, in the thin, moist walls of the alveoli, there is a flow of blood with a low pressure of oxygen, oxygen will diffuse to this region of low pressure or into the blood through the capillary walls. Here the oxygen unites in a loose chemical combination with the hemo-

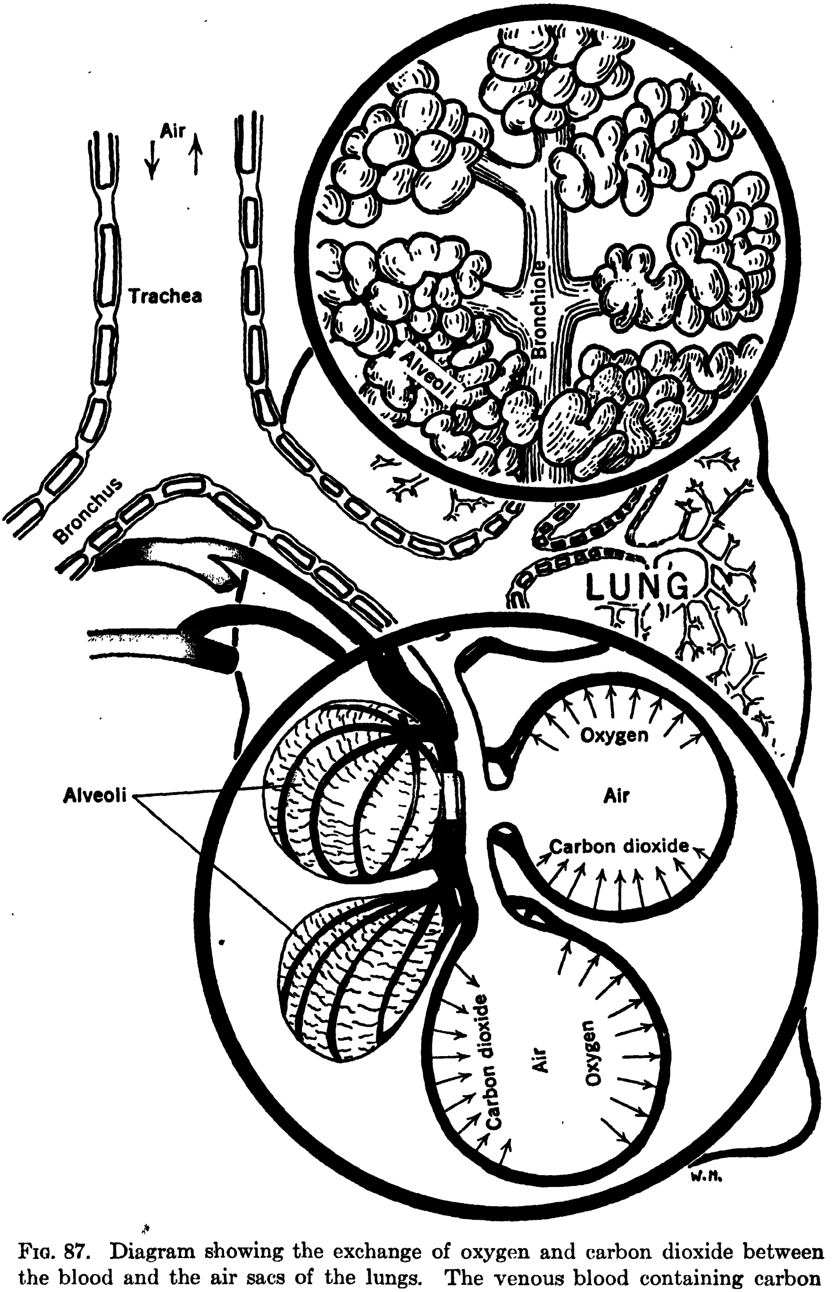


FIG. 87. Diagram showing the exchange of oxygen and carbon dioxide between the blood and the air sacs of the lungs. The venous blood containing carbon dioxide is shown in blue, and the arterial blood, which has lost carbon dioxide and acquired oxygen, is shown in red.

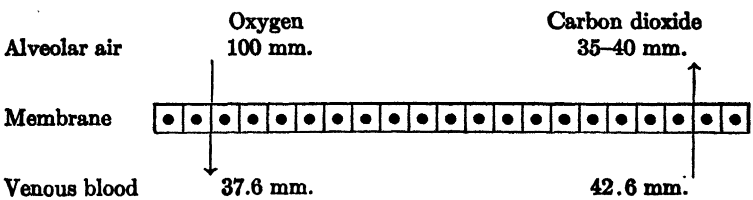
globin of the red corpuscle, forming **oxyhemoglobin,** which is carried along with the blood through the body among the cells of the tissues. These tissues, if they have been releasing energy by oxidation, have a low oxygen pressure. The oxyhemoglobin now readily breaks down into hemoglobin and oxygen, which diffuses through the moist cell membranes to these low-pressure regions in the cells (Fig. 87).

The same general process holds true for carbon dioxide, which we have seen is the product of oxidation. The blood has a lower carbon dioxide pressure than the cell and the tissue fluid that surrounds it. So the carbon dioxide passes through the moist cell membrane and gets into the tissue fluid, whence it finally reaches the blood where some of it may be carried in the plasma proteins and some in the hemoglobin of the red corpuscles. The carbon dioxide is thus carried to the lungs, where the air in the alveoli has a lower carbon dioxide pressure or density than that of the blood. Consequently, the carbon dioxide passes into the air in the lungs and is expelled during expiration. Since gases behave independently of each other, oxygen may be passing into the blood at the same time carbon dioxide is leaving the blood; or vice versa, if conditions are changed.

The somewhat generalized description just given is supported by numerous carefully controlled experiments involving accurate quantitative measurements. The following tables * show the difference in percentage of gaseous content of inspired and expired air and indicate that air in the lungs "loses oxygen and gains carbon dioxide and consequently the blood absorbs oxygen and eliminates carbon dioxide."

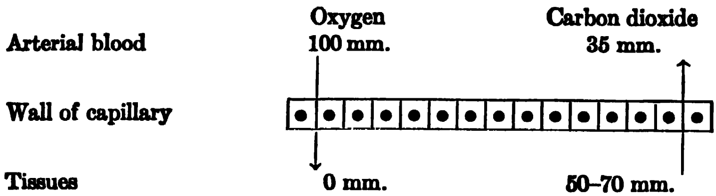
	N	O	CO_2
Inspired	79	20.96	0.04
Expired	79	16.02	4.38
		4.94	4.34

The difference in pressure between the oxygen and carbon dioxide in the blood and those in the alveoli of the lungs is shown by the following summary (arrows show direction of gas flow):



* W. H. Howell, *Textbook of Physiology,* pp. 698, 718, 719, W. B. Saunders Company, by permission.

The difference between the gas tensions in the tissues and those in the arterial blood is summarized as follows:



Regulation of the breathing mechanism in man. Regulation of breathing is brought about by nerve impulses sent out from the **respiratory center** located in the brain (medulla). These impulses go out to the various muscles of the ribs and the diaphragm, initiating movements that cause inspiration and expiration. For the most part, this rhythmic action is automatically controlled, but we can exercise voluntary control to some extent, as when we hold our breath. Apparently the impulses sent out from the brain are influenced by the amount of carbon dioxide in the blood. Thus it can be readily understood that we breathe more rapidly after exercising violently because more carbon dioxide has accumulated in the blood from the muscles and other tissues. Lack of oxygen produces no appreciable effect, but an excess amount of carbon dioxide causes an inspiratory or expiratory impulse to be sent out. When the carbon dioxide reaches a sufficiently high concentration in the blood, it is impossible for a person to hold his breath. One cannot commit suicide by holding the breath. Further effects of carbon dioxide on the body action will be discussed later.

The Breathing Mechanism in Other Animals

From the foregoing discussion we can readily see that for the exchange of gases, oxygen and carbon dioxide, for example, a moist membrane is necessary. Furthermore, the membrane must present an exposed surface sufficient to care for all the oxygen needs of the organism. In the very simplest forms (protozoans and sponges) sufficient body surface is exposed so that no special breathing mechanism is necessary. In the earthworm the oxygen-carbon dioxide problem is solved by a covering of moist skin well supplied with blood capillaries. Some cousins of the earthworm have folds of skin, or special threadlike filaments, which are used in oxygen-carbon dioxide exchange. In many aquatic animals breathing is done by the gills. The water containing oxygen flows over the gills, which take

up oxygen and release carbon dioxide. The gills of crayfish, lobsters, and crabs are feathery plumelike structures. In most mollusks (oysters, clams, squids, water snails) there are specialized folds known as gills which bring about this same exchange. The mantle, a fold of skin which covers the soft visceral structures of certain mollusks, is also a respiratory organ (Figs. 79 and 88).

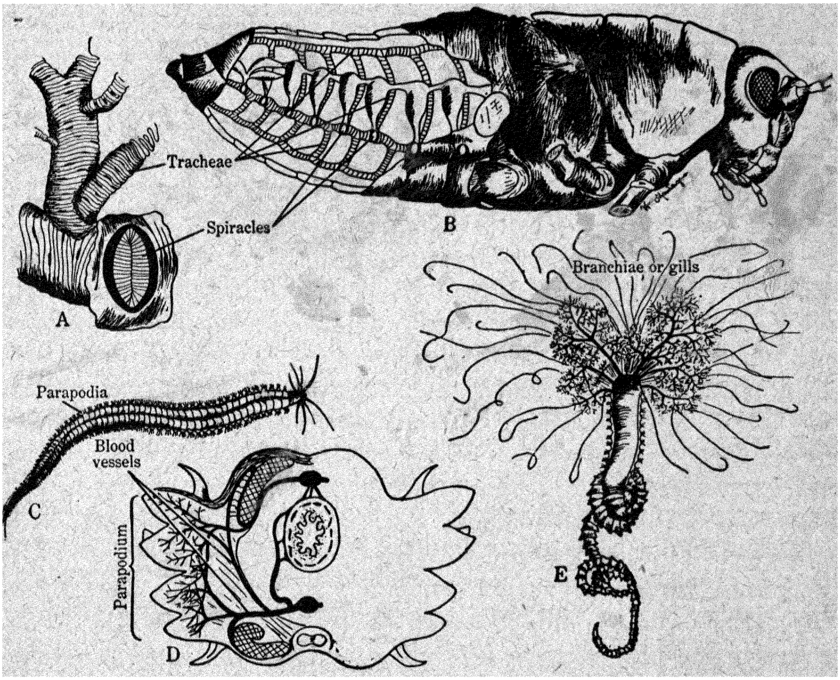


FIG. 88. Breathing mechanisms of other animals. *A* and *B*, insects; *C–E*, worms (annelids). *D, modified from Hegner, "Invertebrate Zoology"; E, redrawn from Parker and Haswell, "Textbook of Zoology," Vol. I. By permission of the publisher, the Macmillan Co.*

In adult insects and some related animals the air enters the respiratory tract through small pores in the body wall, called **spiracles.** The spiracles lead into a system of tubes called **tracheae** which resemble only superficially the trachea of man. These tubes made of spirally twisted tissue branch, divide, subdivide, and end in very minute vessels which carry the air with its oxygen directly to the tissues. Carbon dioxide is expelled through these same tubes. The air is exhaled and inhaled by contractions of the body wall, and the rate of these contractions is dependent upon and varies with the activities of the insect. The blood of such animals has little to do with oxygen and

carbon dioxide distribution. Spiders exchange oxygen and carbon dioxide by means of folds of tissue called "book lungs." In some animals, such as insect larvae (dragonflies), the hind gut or cloaca is very vascular and is used in breathing.

In fishes, **gill slits** lead from the pharynx and open to the exterior. The **gill arches** or the walls of the gill slits are supported by either bony or cartilaginous rods and are used for the attachment of very delicate, highly vascular gills. The water containing dissolved oxygen enters the mouth and flows through the gill slits over the gills to the exterior. Gills of tadpoles and salamanders are usually bushy in type. It is to be noted that one of the main principles in breathing devices is the provision of a maximum amount of moist surface with a minimum of bulkiness (Figs. 87 and 88).

With some modification, the general plan of the breathing mechanism described for man is the same in practically all vertebrates other than fishes. In frogs these is no diaphragm. The closing of the nostrils and raising of the floor of the mouth force air from the pharynx into the rather simple saclike lungs. Thus, in a sense, the air is swallowed. The lungs of birds are attached to the ribs. When the bird is not flying, inspiration and expiration take place respectively by the raising and lowering of the chest. In addition to lungs, birds have large accessory air sacs located in some of the bones. These sacs increase the breathing surface to a large degree and function especially when the bird is flying. In flight the bird's powerful wing muscles must have a firm anchorage. This is furnished by the ribs, which are held rigid by the contracted rib-muscles which cannot now function effectively in ordinary breathing. Under such conditions, the air sacs, which are filled and emptied in flight, serve to bring about inspiration and expiration through the lungs. There are no vocal cords in the larynx of birds, but the sounds are developed by a vibratory membrane in the **syrinx** (*syrinx*—a pipe), a special structure located in the trachea just before it divides to form the bronchi.

EARLY HISTORY OF RESPIRATION

One of the earliest respiration experiments on record was performed by Robert Hooke in 1667. He demonstrated before the Royal Society that in order to be kept alive a dog must have a "sufficient supply of fresh air." A little later (1674) John Mayow conceived the idea that air contained a specific substance which was necessary to support combustion and to maintain vital activity. He wrote as follows: "With respect, then, to the use of respiration, it may be affirmed that

an aerial something, whatever it may be, essential to life, passes into the mass of blood. And thus air driven out of the lungs, these vital particles having been drained from it, is no longer fit for breathing again." He called this substance the *spiritus nitro aereus*, and of course this was a shrewd guess at what we now recognize as oxygen. Priestley discovered oxygen a century later (1774), but he called it "dephlogisticated air," i.e., air deprived of **phlogiston,** which, according to this theory, was a specific substance in matter that was liberated by burning. Priestley's experiment revealed the fact that, after air had been "spoilt" by the respiration of animals, it could be restored by the activity of green plants if exposed to sunlight. However, it was the brilliant Frenchman Lavoisier who discovered the real nature of respiration and who gave to the world the correct interpretation of the chemistry of combustion. By carefully weighing his materials he was able to account for changes that had hitherto been unnoticed, and by a series of excellent scientific experiments he ascertained that respiration is a chemical process which consumes the oxygen of the air and produces carbon dioxide.

SUMMARY

In plants, respiration, like digestion, takes place in all living cells. There is no highly specialized mechanism for supplying oxygen and removing carbon dioxide such as there is in animals. Air diffuses into the leaves through the stomas. Oxygen dissolves in the water of the cell walls and diffuses into the cells. Carbon dioxide diffuses from the moist cell walls into the intercellular spaces and out through the stomatal pores. As we have already observed, the interchange of these two gases is reversed in photosynthesis.

Also, we have seen that in most animals special structures are developed to insure a supply of oxygen to every component cell and to carry away the carbon dioxide. Among these special devices are gills, tracheae, and lungs: The gases move in and out of the tissues according to the physical laws of gases. In most animals the blood is the medium by which oxygen and carbon dioxide are distributed, but there are exceptions in insects and some other animals.

CHAPTER VII

METABOLISM (*Continued*). WHAT OTHER WASTE MATERIALS ARE PRODUCED AND ELIMINATED? THE CYCLES IN NATURE

We have learned that many and varied chemical changes take place in plant and animal cells; that some of these changes store up energy and that others release this energy in the performance of the different functions necessary to support vital activity. In the course of these changes, especially those involved in catabolism, many compounds are formed which are not used in growth or repair and which do not again enter into the metabolism of the cells. Such substances are usually called waste products. Some of them may be of service to the organism, whereas the accumulation of others would be extremely harmful and might even result in death. Throughout its life, the organism provides, in one way or another, for the elimination of all harmful wastes.

PLANT WASTES

In plants it is difficult and very often impossible to discriminate between secreted products that may be useful and those that are truly waste products. However, in both the decomposition and synthesis of useful materials wastes are formed, so we may conclude that many kinds of wastes are produced in the living cells. Little is known about the chemical reactions that are responsible for the production of waste materials and the special conditions that induce these reactions. We are more familiar with the substances formed in the reactions. We have already seen that, in the process of photosynthesis, oxygen is given off as a by-product. Likewise carbon dioxide is a waste in the process of respiration.

Disposal of wastes. The dropping of roots, twigs, leaves and the exfoliation (shedding) of bark dispose of some wastes. Small quantities are eliminated in the secretions of surface glands and by diffusion from roots. Diffusion of wastes from various other parts may occur in submerged water plants. In most plants, however, there is no special mechanism of elimination, such as the skin and kidneys

of animals, and wastes are merely stored in some out-of-the-way place within the body of the plant.

Gaseous wastes. When green plants are exposed to light under favorable conditions of moisture and temperature, photosynthesis exceeds respiratory activity and oxygen diffuses from the plant into the air as a waste product. Under such conditions the carbon dioxide produced in respiration may not be eliminated but may be used largely in food manufacture. During the hours of darkness the carbon dioxide produced by respiratory activity in the roots and in all other parts of the plant diffuses out of the cells as a gaseous waste. The carbon dioxide diffusing from roots combines with water in the soil to form carbonic acid, which aids in dissolving the mineral salts, thus facilitating their diffusion into the root hairs.

Some plants, such as cotton and vermifuge and the flowers of hawthorns, emit a disagreeable odor owing to the escape of the gas called trimethylamin. In the cotton plant this gas is said to attract the moth of the cotton bollworm, so that a waste product here becomes an active agent in abeting one of the greatest enemies of the cotton industry.

Root excretions. There is evidence to show that roots excrete various substances, among which are enzymes involved in extracellular oxidations. When plants are grown with a limited supply of oxygen such organic acids as oxalic and formic acids are excreted by the roots.

Formerly it was believed that the excretions from the roots of one crop of plants would be injurious to the roots of a succeeding crop. For example, it was reported that the roots of the common black walnut tree excrete an organic compound that is toxic to the roots of apple trees, and that apple trees will die if their roots come in contact with the roots of walnut trees. A similar toxic effect was thought to be exerted by one crop of cereals on a succeeding crop of a different cereal. To evade this possibility, a theory of crop rotation was proposed. Although the problem is not yet definitely solved, "it is now rather well established that the roots of plants do not excrete substances that are beneficial or detrimental to either accompanying or succeeding crops." * The harmful effect of one crop on a succeeding crop is now quite generally believed to be caused by the presence of complex organic compounds formed by the bacterial decomposition of any fragments of the plants that remain in the soil.

Essential oils. Many plants secrete volatile oils known as **essential oils,** which, as they have no further role in metabolism, may be regarded as waste products. These oils are called essential oils because they are utilized in the preparation of essences and perfumery. Most of the odors of plants are due to the presence of essential oils, which

* E. C. Miller, *Plant Physiology,* p. 164, The Macmillan Company, 1938.

constitute a part of the complex mixtures secreted by glands of various kinds. The odor of onions and garlic, the flavor of the orange, and the fragrance of the rose may all be accounted for by the presence of essential oils representing waste products formed in the plants. The volatile oils are in no way chemically related to the so-called true oils and, unlike them, when placed on glazed paper

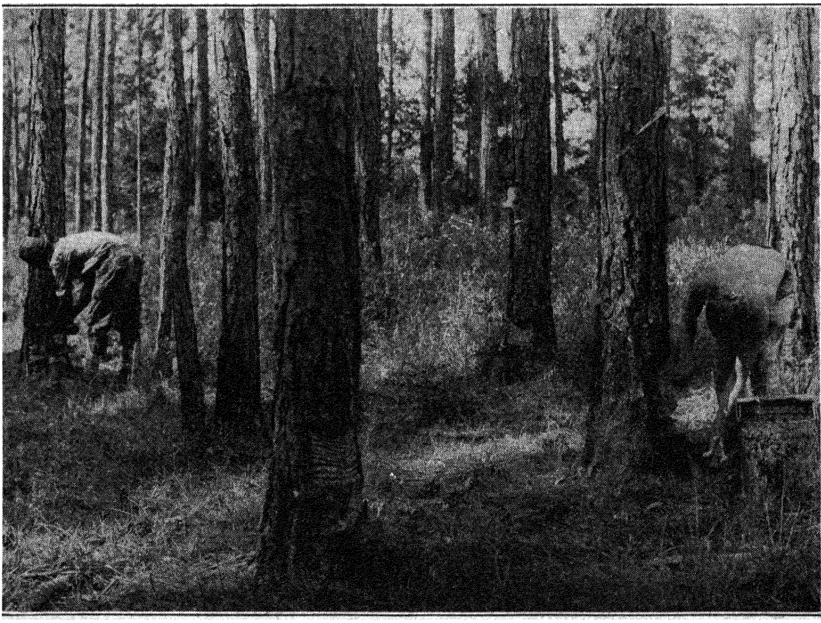


FIG. 89. Collecting resin from pine trees. *Photograph furnished by U. S. Department of Agriculture (photograph S6801 by Hunton).*

leave only a transient spot or stain. Essential oils may be produced or stored in any part of the plant but are generally most abundant in the foliage and flowers, from which they may be distilled or pressed out (Fig. 90). After purification, some of the essential oils are used in medicines and others as perfumes, either directly or indirectly, in ointments, soaps, shaving lotions, face powder, hair dressings, and other toilet accessories. Camphor, oil of cedar, oil of lemon, oil of cloves, thymol, and menthol are essential oils having many commercial applications.

Gums and resins. These wastes may occur separately or in mixtures known as gum resins, or balsams, which exude from wounds and solidify in drops and irregular masses. True gums consist mainly of carbohydrates and are formed by changes in the cell wall and

growing tissues of woody plants. The gum of peach and cherry trees is a common example. Resins occur dissolved in the essential oils; e.g., turpentine consists of colophony (a resin) dissolved in "oil of turpentine" (Figs. 89 and 90). Gum resins such as asafetida

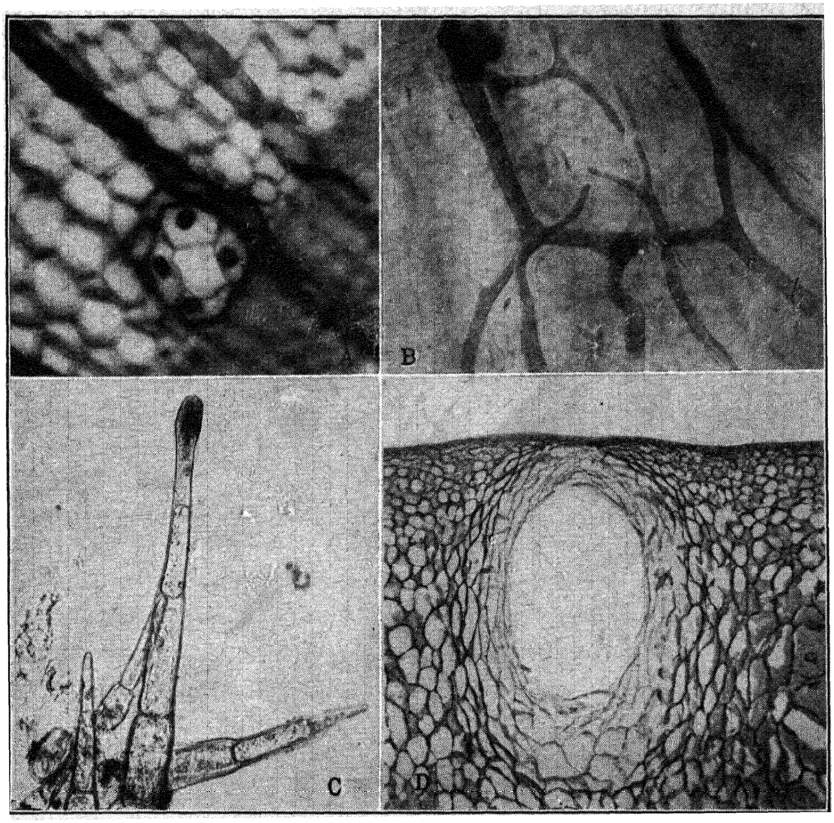


FIG. 90. Various plant wastes: *A*, cross section of resin duct in pine wood; *B*, latex vessels; *C*, glandular hair; *D*, oil gland of orange peel. *Photomicrographs furnished by H. Lee Dean.*

may be used in medicines; others, like galbanum, myrrh, and frankincense, form the principal components of incense.

Organic acids. Oxalic, tartaric, citric, and other organic acids are products of the incomplete oxidation of carbohydrates. Every living cell contains some organic acid or acids, and this fact accounts for the acid reaction normally given by the cell sap. The calcium salt of oxalic acid is widely distributed in the cells of many plants, and, since calcium oxalate crystals are abundant in the leaves and bark which finally fall from the tree, some authors regard this as a means

of eliminating excess amounts of oxalic acid. External conditions have a marked influence on the formation of organic acids; e.g., the amount of acid present increases in darkness and decreases at high temperature.

Tannins and alkaloids. Tannins are bitter astringent compounds widely distributed in plant tissues, but occurring most abundantly in bark, wood, leaves, fruits, and galls. Their value in treating hides to make leather is explained by the fact that they precipitate the gelatin in the skins. When tannins react with iron salts, blue or green colors are produced; consequently, tannins were formerly much used in the making of inks. Tea leaves contain much tannin. Alkaloids are bitter, usually odorless, nitrogen-containing compounds that have marked physiological effects upon animals. Common alkaloids are nicotine from tobacco, caffeine from tea and coffee, quinine from cinchona bark, atropine from nightshade, and morphine from the poppy. They are very important medicinally, being much used as stimulants and narcotics. As drugs, they must be administered wisely, for all alkaloids are dangerous poisons when taken too frequently or in too large quantities.

Pigments. Many pigments found in leaves, flowers, fruits, bark, and seeds must also be regarded as plant wastes. The most common of these pigments are the anthocyanins, which, dissolved in the cell sap, are responsible for red, blue, and purple colors, depending on whether the dissolving medium is acid, alkaline, or neutral. Apparently, the presence of sugars is the main factor inducing the formation of anthocyanins, and, since low temperatures favor the storage of carbohydrates, we can readily understand why red leaves and shoots are so prevalent during early spring and late autumn.

Minerals. Such minerals as calcium and silicon may be regarded as waste products when it can be demonstrated that the plant makes no use of them. The calcium oxalate crystals previously mentioned and the silica deposited in the cell wall seem to be waste materials. Silica is always present in the stems and leaves of the corn plant, but apparently not as an essential element. It has been shown that four generations of corn may be grown with practically no silica. Likewise it is apparent, in some individuals at least, that the presence of certain minerals is not determined by the requirements of the plant but by the simple fact that the molecules of the solute were permitted to diffuse into the cells.

TRANSPIRATION

We shall also consider here the subject of water loss, which in the plant is probably not a true excretory function but, since it represents the elimination of a gaseous waste (water vapor), may appropriately be discussed in this connection. The evaporation of water from the aerial parts is perhaps the most important movement of material from the plant. This water loss was first called **transpiration** (*trans*—across; *spiro*—I breathe) because it was thought to be a process similar to the movement of water vapor from the lungs of animals.

Although transpiration is one of the most important functions of leaves, we should not think of it as a specific physiological process. Whenever a water surface is exposed, water molecules detach themselves and diffuse into the air, a process called vaporization or evaporation. Similarly, when a plant is exposed to the air, under ordinary conditions, water molecules escape from the mesophyll cells into the saturated air of the intercellular spaces and thence, through the stomas, into the less-saturated external air. Thus we see that transpiration is a purely physical process the same as evaporation from a wet sponge or towel and may take place in either living or nonliving structures. There is no reason to suspect that transpiration depends upon the activity of living cells.

Some molecules may also pass directly through the walls of the epidermal cells into the surrounding atmosphere, but, in those leaves possessing a well-defined cuticle, molecular movement through the walls of the epidermal cells is relatively slight. It has been estimated that 80–97 per cent of the water loss occurs by diffusion through the stomas.

Amount of transpiration. Few people appreciate the surprisingly large amounts of water transpired by plants. On a warm day a large sunflower plant evaporates more than a quart of water, and a well-watered corn plant may lose 40 gallons of water during its life. The quantity of water lost in transpiration exceeds many times the amounts used in photosynthesis and the synthesis of other organic materials.

A field of wheat during its entire period of development evaporates an amount of water sufficient to cover the field to a depth of 4 or 5 inches. An acre of corn plants may lose 48 tons of water in a day, and it is estimated that during a season these plants will use 1,700 tons of water in transpiration and 4½

tons in photosynthesis (Fig. 91). Of course, the amounts of water transpired vary with the species and with changes in the surrounding conditions.

The ratio of the total amount of water taken up by the plant during its period of growth to the total dry weight of the plant at the end of this period

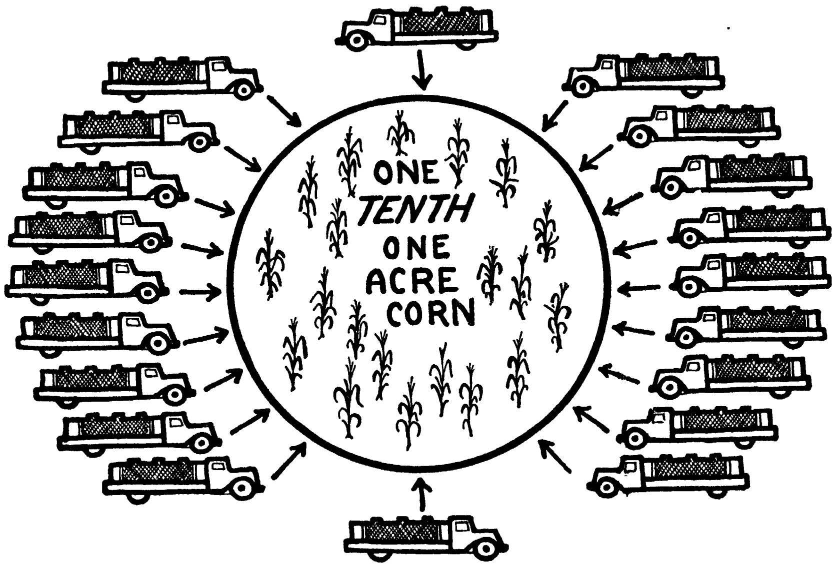


Fig. 91. The amount of water transpired by $\frac{1}{10}$ of an acre of corn in a season would fill 20 gasoline trucks.

is called the **water requirement.** The accompanying table shows the pounds of water required to produce a pound of dry weight in some common plants and indicates the range of variation in the water requirement of different plants.

Sorghum	250	Cucumber	713
Corn	350	Alfalfa	900
Red Clover	460	Wheat	500
Potato	636		

It has been demonstrated that crop plants grown in the central portion of the United States require 300 to 500 pounds of water for every pound of solid matter produced in the aerial parts of the plants. At Akron, Colorado, where the climate is much drier the water requirement for these same crop plants is from 400 to 1,000 pounds.

Significance of transpiration. Much has been written about the relative advantage of transpiration. Some authors have even considered it a "necessary evil." When we think of the relatively large amounts of water lost through the stomas we are sure to conclude that more water moves through the plant than would actually be needed if transpiration did not occur. Thus transpiration might be

considered detrimental to the plant. However, since most of the light energy absorbed by the leaf is transformed into heat, the internal temperature might soon reach a point where it would injure the protoplasm. But this heat energy is transformed into molecular motion, increasing evaporation and thus cooling the leaf, just as evaporation of moisture from the face or hands cools them. Consequently, the temperature of the leaf tissues is actually maintained within a few degrees of that of the air. In addition to its service as a regulator of leaf temperature, transpiration is an important agent in raising water and mineral salts from the roots to the leaves.

Regulation of transpiration. Certain structural features of leaves are of some advantage in lowering the rate of transpiration (Fig. 92). Compact cell arrangement, thickening of the cuticle, reduction of leaf size or total leaf area, and shedding of a portion or all of the leaves during periods of drought are advantageous in reducing water loss. The epidermal cells of some leaves excrete a fatty material which accumulates as a layer of wax particles forming an almost impervious coating known as "bloom." This coating may be seen on the leaves of cabbage, on such fruits as the grape and plum, and on the surface of young raspberry canes. Resins, gums, and mucilage are substances that also tend to reduce transpiration. Plants like cactus, with a large water-holding capacity, usually develop a considerable amount of mucilage which has a strong imbibing power.

Formerly epidermal hairs were thought to be of some importance in checking transpiration, but experiments have revealed that the rate of transpiration from the densely hairy leaves of mullein is about the same as that from tobacco leaves lacking such a hairy covering. It is now rather well established that epidermal hairs do not reduce water loss significantly. Such hairy coats will not prevent excessive water loss from plants growing in extremely dry places, nor will they render it possible for plants to maintain themselves in dry situations.

Influenced by light, temperature, internal water relations, and perhaps other factors, the acidity of the guard cells fluctuates from time to time. Apparently, the guard cells always contain starch, and when the acidity decreases, the enzyme diastase becomes active and insoluble starch is converted to soluble sugar. Thus the water becomes diluted, forming a diffusion gradient along which the water molecules from the adjacent cells move by osmosis into the guard cells, increasing their turgor. The increased turgor stretches the walls, but, since they are thicker and less tensile on the side next to the opening, the cells do not assume a spherical shape but become bean-shaped with their concavities adjacent to the stoma, which is thus considerably enlarged. This series of reactions is usually promoted by light. With darkness, acidity of the guard cells increases, sugar is synthesized into insoluble starch, water passes by osmosis out into the adjacent cells, and the turgor decreases. The elasticity of the walls of the guard cells causes them to assume their original, more

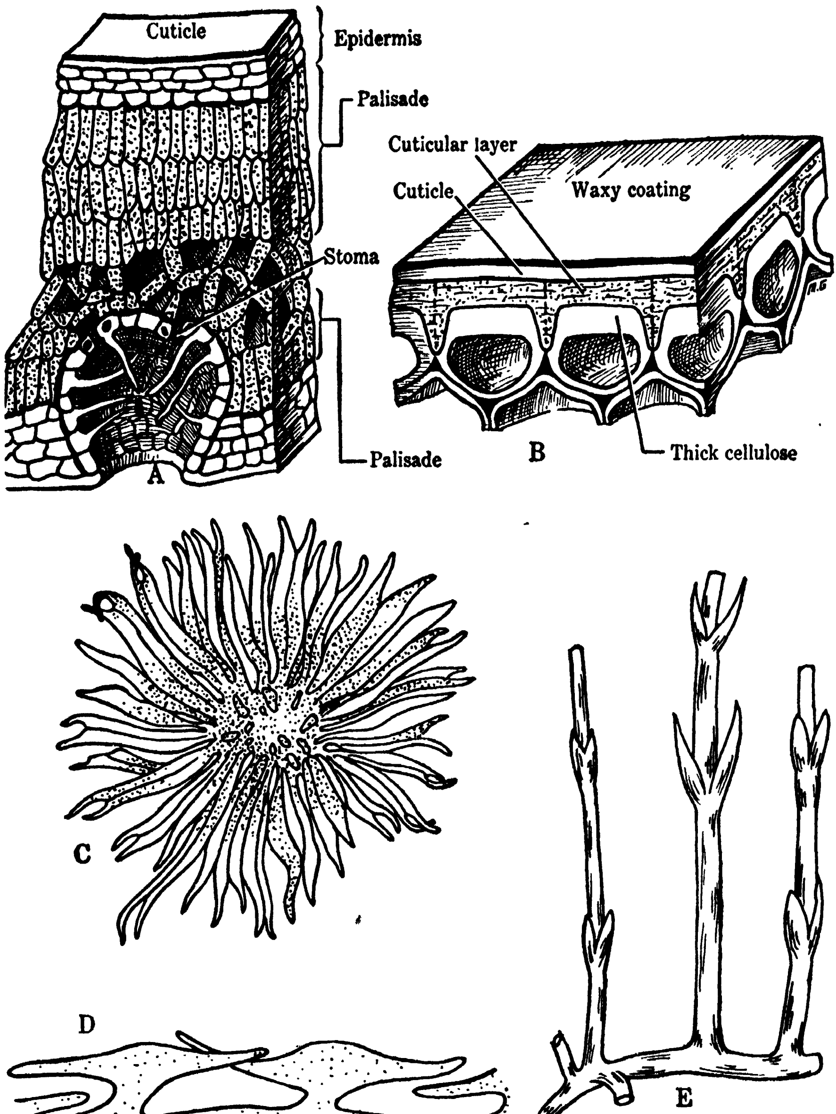


FIG. 92. Some structural features that reduce transpiration. *A*, stomas at the bottom of a hair-lined pit (*Oleander*). *B*, epidermis of xerophytic grass. *C*, a scale from the epidermis of "Spanish moss" (*Tillandsia*). *D*, a section showing overlapping of these scales. *E*, reduced scalelike leaves of *Ephedra*. *B–E, after Coulter, Barnes, and Cowles, "Textbook of Botany." By permission of the publisher, the American Book Co.*

rounded contour, thus closing or almost closing the opening between them. However, even in darkness, if the temperature is relatively high, the acidity of the guard cells may be reduced, and under such conditions the stomas would remain open, despite the absence of light. If the water content of the guard cells is low, their turgor may be so reduced that the stomas remain closed during the day. Thus when leaves wilt, the stomas usually, but by no means invariably, close. Although this explanation serves to give some appreciation of the mechanism involved in stomatal opening and closing, it must be remembered that the behavior of guard cells is not uniform in all species of plants. For example, the stomas of the potato plant usually remain open continuously except for about 3 hours after sundown.

These movements of the guard cells also regulate the exchange of carbon dioxide and oxygen as well as that of water vapor. But this mechanism must not be considered a means of conserving water in the plant, for the stomas open under the influence of light, even though the plant may have an inadequate water supply, and they may close when the plant has an abundance of water.

Influence of external factors. Any factors that tend to modify the rate of evaporation also change the rate of transpiration. A dry atmosphere tends to increase transpiration; a moist atmosphere reduces it. The amount of available water in the soil is also an important factor. Light accelerates transpiration in two ways: by bringing about an enlargement of the stomatal openings and by increasing the temperature. Thus we can readily see that external factors exert a very marked influence on transpiration and often are responsible for internal changes in structure, or organization, or both, which, in turn, may change the rate of transpiration.

Guttation. This is often observed in young leaves while rapid growth is taking place. It may be demonstrated by placing a pot of corn or wheat seedlings in a moist chamber. Within a few hours, drops of clear water will be seen hanging from the tips of the leaves. This phenomenon is known as **guttation** (*gutta*—drop). The water is secreted by a special tissue lying near the end of the leaf. In transpiration, as already noted, water leaves the plant in the form of vapor, but in guttation water is exuded in the liquid state.

Role of water in the plant. The importance of water in the activities of the plant is comparable to the necessary role it has in many factories where different kinds of materials are produced. In almost every factory it is a solvent and cleanser, a carrier and cooler, a building material, and a necessary chemical reagent. Great quantities of water are taken into the factory, where it enters into most if not all of the functions taking place. After its work is done, except for the small amounts retained for structural use, the water leaves the factory as waste. Of course, the water that leaves the plant

as vapor will be recondensed and, in some form of precipitation, will be returned to the soil, whence it can be absorbed again by the roots and returned to its role in the functions of the plant.

ANIMAL WASTES—EXCRETION

It has already been pointed out that energy is released by the oxidation of stored carbohydrates, fats, and proteins. Even the living tissues may be broken down and their proteins and fats oxidized. In plants there are no special organs of elimination, but in animals such organs are usually present. In addition to the elimination of the products of metabolism, excretion in both animals and plants regulates the temperature of the organism to some degree and disposes of excess water in the tissues, as has already been seen in transpiration and guttation in plants.

Animal wastes are of several sorts. Because of differences in food supply and in the metabolic processes themselves, wastes may vary somewhat from animal to animal and even in the same individual from time to time. Animal wastes such as carbon dioxide or urea may be products of metabolism, or they may be toxic substances formed by the animal body under either normal or diseased conditions. Other cast-off materials termed wastes, but not direct byproducts of metabolic processes, are indigestible substances and unabsorbed food which accumulate in the lower end of the alimentary canal and dead scaly portions of the skin which are worn away and sloughed off daily. The horny covering of the crayfish, the skins of snakes, feathers of birds, antlers of the deer, and the hair and horns of other animals are shed periodically. In many animals, including organisms so different as man and the earthworm, the outer protective covering is continually sloughing away and continually being restored.

The simplest animals have no highly complex excretory organs, and much of the waste is eliminated from each individual cell directly into the environment. However, these wastes are very similar in nature to the wastes of the highest animals. As we come up the scale in animal complexity, as will be shown later, higher animals develop a great variety of excretory organs.

Carbon dioxide. It may be recalled that carbon dioxide, together with water, is formed for the most part by oxidation of carbohydrates and fats, although some of these wastes may come from digested protein not used in tissue building. In the lower animals, carbon dioxide is eliminated mostly through the body surface, but in the

more complex invertebrates other devices are involved, such as the tracheae of insects and various types of gill-like structures. In the vertebrate animals carbon dioxide is thrown off in greatest amounts by the lungs or gills, and in lesser amounts through the skin. In man very little carbon dioxide is eliminated by the skin.

Water. Although the lungs and skin eliminate water, probably the most important structures involved in water regulation are the

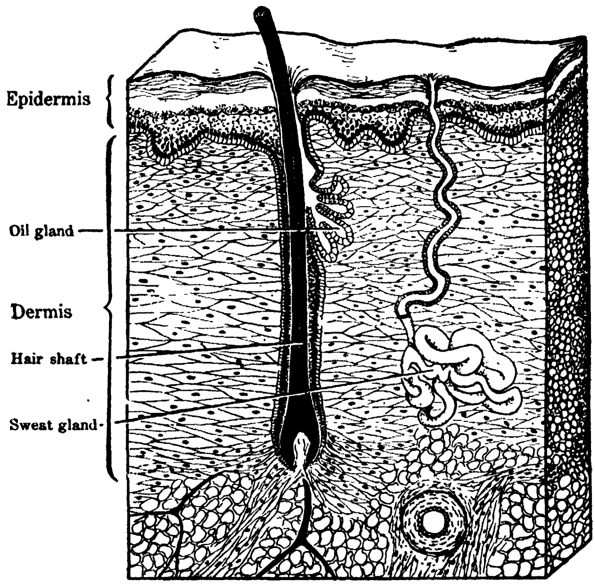


FIG. 93. Diagram of a section of the skin.

kidneys. The relative importance of these mechanisms varies with different animals. Water is given off from the skin of various vertebrates in two ways: by the secretion of sweat glands, and by evaporation from the general epithelial surface. In man, the **sweat glands**—there are over 3,000,000 of them—are tubular glands whose internal, coiled, terminal region is well supplied with blood vessels (Fig. 93). From the blood in these vessels the gland removes some of the excess moisture, which is excreted as sweat. In composition sweat resembles very dilute urine; it varies in amount with both the individual and his activities.

It may be recalled that a moist membrane is necessary for gaseous exchange. Thus the lining membrane of the lungs must be kept moist. The moisture, supplied by the blood, is constantly diminished by evaporation and is lost with each expiration in the form

of vapor. To bring about this change, just as to change water into steam, heat is required. In the organism, heat comes from the oxidation of various compounds in the cells, which in turn heats the blood as it courses through the organism. In the lungs and skin the blood loses some of its heat and water by evaporation. Thus cooled, the blood as it circulates cools the tissues and in a large measure controls the temperature of the organism. It is estimated that, of the heat loss in man, 85 per cent is lost from skin, 10 per cent in breathing, and 5 per cent in warming food and air.

Increase in oxidation may be brought about by muscular exertion, which, in turn, causes a greater activity of the sweat glands and more water (sweat) is secreted, which, evaporating, absorbs more heat. Shivering is a type of involuntary muscular exercise. Dogs may adjust their temperature to some extent by panting. Excessive cold results in a contraction of the blood vessels of the skin, cutting down the supply of blood to these regions so that less heat is lost. The temperature of an animal is influenced by other factors, such as the accumulation of an insulating layer of fat under the skin, the development of such protective structures as hair, feathers, and scales, and the wearing of clothes.

Certain animals such as men, dogs, cats, and birds have a fairly constant temperature irrespective of the environment. Such animals are known as **warm blooded.** The body temperature of other animals varies directly with the temperature of the environment; such animals are called **cold blooded.** Among the cold-blooded animals are frogs, fishes, and snakes, whose body temperature is usually only a few degrees above that of the environment. This fact accounts for the cold "feel" of a fish, frog, or snake; since the temperature of these animals is approximately that of the environment, the animals feel cold when touched by our "warm-blooded" hands.

Nitrogen compounds. These, as well as sulphates, phosphates, and other waste products of protein metabolism, are excreted, for the most part, by the kidneys, in the form of a watery solution called **urine.** In man, the kidneys are located in the abdominal region on either side of the backbone at about the level of the lowest ribs. The urine is drained from them by two tubes, the **ureters,** emptying into a muscular reservoir, the **urinary bladder,** which empties through a tube, the **urethra** (Fig. 94). In some animals, such as birds, the urinary bladder is missing and the ureters empty into the cloaca. In frogs, the ureters carry the urine to the cloaca whence it passes through a ventral opening into a urinary bladder. The accumulated

urine is later voided through this opening into the cloaca and thence to the outside.

The kidney. To understand more clearly the mechanism of the urinary system, some knowledge of the detailed anatomy of the kidney is necessary. We shall first examine the comparatively simple "kidney" of the earthworm. The coelom of an earthworm is divided into compartments filled with coelomic fluid in which waste

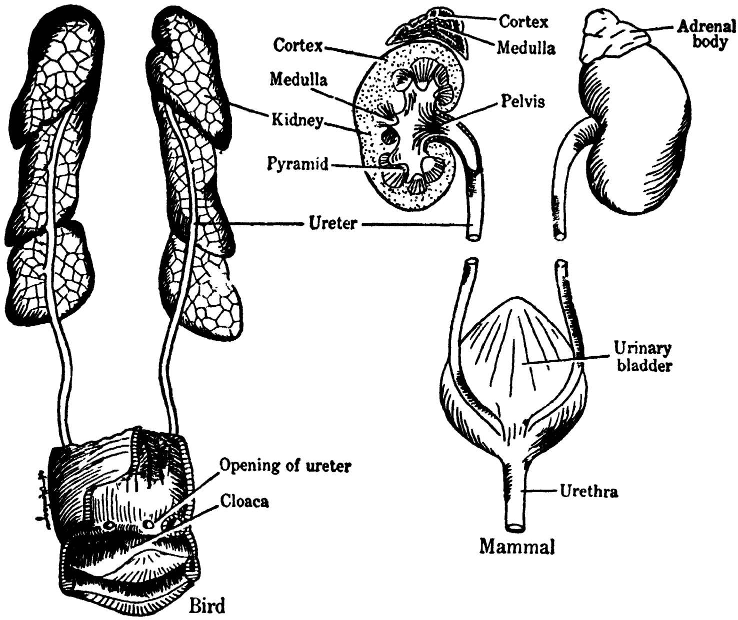


FIG. 94. Urinary systems of a bird (chicken) and a mammal (man).

material may be found. In most of these compartments are pairs of small, looped tubes called **nephridia** (*nephros*—kidney), which open into the coelom by ciliated funnels called **nephrostomes** (*nephros; stoma*—mouth) (Fig. 95). Beyond the looped region each nephridium empties to the outside through a pore in the body wall. The looped part of each nephridium is closely invested with blood vessels from which waste material may be extracted and discharged to the exterior through the nephridial tube. The waving cilia of the nephrostome create a current in the coelomic fluid which causes the wastes in this fluid to move into and through the nephridial tubule to the outside.

In the kidneys of reptiles, birds, and mammals the tubules are much more localized or closely aggregated than in fishes and am-

phibians, and no nephrostomes are present. Two main regions can be distinguished in this kidney—an outer zone called the **cortex,** where most of the secreting structures are located, and an inner **medullary region** made up mostly of **collecting tubules.** A unit of this secreting mechanism consists of a knot or mesh of blood vessels (arterioles) called a **glomerulus** (*glomus*—ball of yarn) enclosed in a double-

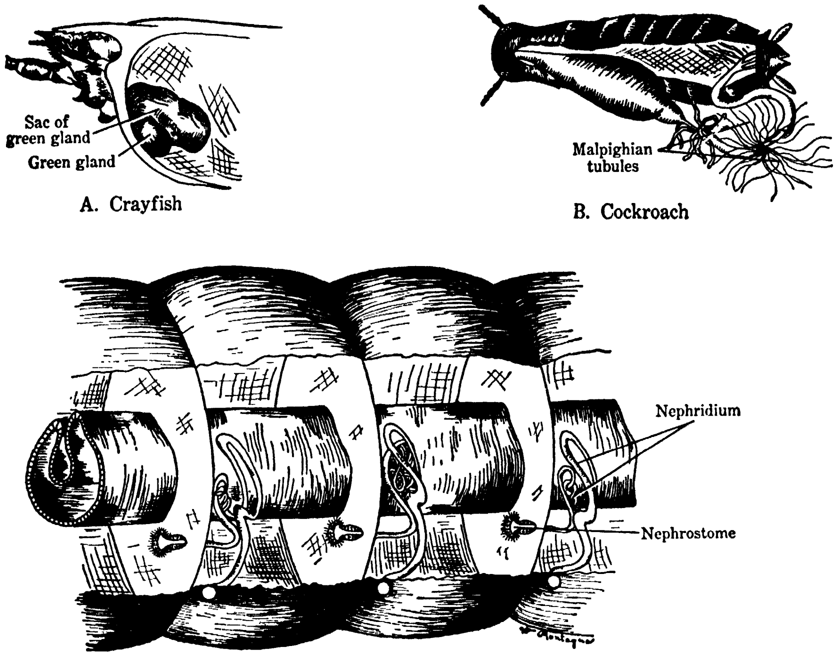


FIG. 95. Kidneys of invertebrates. *A, after Huxley. B, redrawn from Comstock, "A Manual for the Study of Insects." By permission of the publisher, the Comstock Publishing Co.*

walled capsule called **Bowman's capsule.** The glomerulus and capsule form a **Malpighian body** (Fig. 96). Bowman's capsule in a sense is the indented end of a rather complex, looped **secreting tubule.** The many secreting tubules join the collecting tubules in the medullary region of the kidney. The smaller collecting tubules in turn join each other to form larger drainage tubules which discharge the urine into the funnel-shaped end of the **ureter.**

The mechanics of the kidney. The blood enters the glomerulus of the kidney through an **afferent vessel** and leaves by the **efferent vessel.** The smaller diameter of the efferent vessel subjects the blood to increased pressure in the glomerulus so that, as it passes

through the glomerulus, it loses water, glucose, urea, and other salts, which make up the urine. Urea, one of the main constituents of the urine, is the result of the complete breakdown (deamination) of excess amino acids in the liver. After leaving the glomerulus, the efferent artery forms a dense network about the secreting parts of the

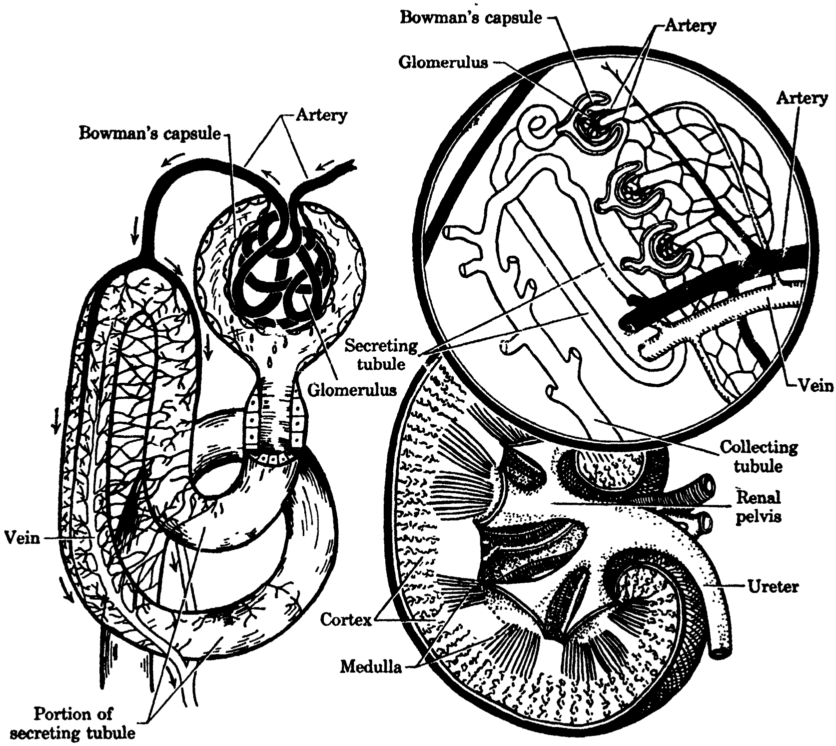


FIG. 96. Anatomy of the human kidney. Shown in circle is a diagram of the structure of the cortex.

tubule (Fig. 96). The water or urine, as it leaves the glomerulus and enters the secreting tubule, contains glucose, urea, and other salts in a very dilute solution. As the urine passes down the tubule, much of the water is resorbed as well as glucose and some of the other substances previously filtered out in the glomerulus. The result is that the urine entering the urinary bladder is a much more concentrated solution and of a composition different from that of the liquid leaving the glomerulus. For example, bladder urine normally contains no glucose but has a concentration of urea 70 times greater than that existing in the blood.

The experimental work leading to the discovery of the functioning of the kidney described above is quite interesting. By careful manipulation it was possible to insert a quartz tube of microscopic dimensions into Bowman's capsule and to draw off enough urine for chemical analysis. This analysis showed that the composition of glomerular urine was practically the same as that of the plasma of the blood except that the proteins were missing. The relative concentration and composition of glomerular urine as compared with bladder urine, as already described, was revealed by this analysis. In another experiment, microscopical examination showed that when dyes are injected into the blood they filter out into the glomerular urine, which deepens in color as it trickles down the secreting tubules.

THE CYCLES IN NATURE

The ultimate fate of plant and animal bodies. We have been considering the wastes formed in the cells of living organisms and the elimination of these wastes. From what has been said we may infer that dead cells may be disintegrated and eliminated from the organism like other wastes. The question that now arises is what becomes of the material of the organism after it finally dies. The final disposal of wastes and dead matter involve two very important series of events, viz., the **carbon cycle** and the **nitrogen cycle.**

The role of bacteria and fungi. When living organisms die their dead bodies are disintegrated by various plants and animals which feed on them. The digestive and respiratory activities of all animals, including man, bring about a dissolution of plant and animal tissues. The organic material itself is gradually disintegrated, forming increasingly simpler compounds until finally all the carbon is completely oxidized and returned to the atmosphere as carbon dioxide. Two very important groups of plants involved in this work of decomposition are the **bacteria** and **fungi,** concerning which we shall learn more at a later time. When these plants attack tissues, they induce a decomposition commonly spoken of as rotting or decay. One of the end products of decay is carbon dioxide. Thus we see that, by combustion of gas, wood, coal, and other substances, by oxidation in living plants and animals, and by the disintegrating processes of decay carried on by bacteria and fungi, the carbon dioxide supply of the air is constantly being renewed. Green plants use the carbon dioxide and build the carbon into carbohydrates which are the building stones of fats and proteins. When these organic compounds are again completely broken down, carbon dioxide is formed once more,

and in this way a perpetual cycle is maintained through which carbon functions as the principal constant. This is known as the **carbon cycle** (Fig. 97).

Since proteins are always present in protoplasm and since all proteins contain nitrogen, it is evident that substances other than carbon dioxide must be formed when dead organisms are disintegrated. The complete decomposition of the proteins is effected by different relays of bacterial organisms. The odor of decaying organic bodies always

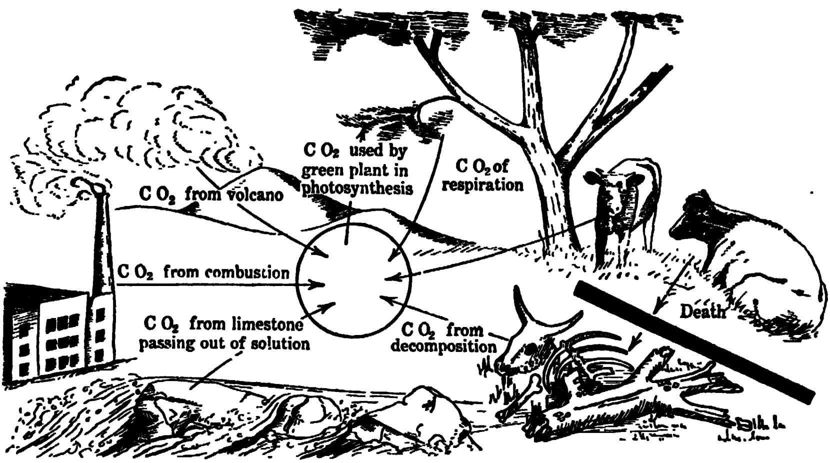


FIG. 97. Diagram of the carbon cycle.

reveals the presence of ammonia (NH_3). Ammonia is derived from the breaking down of the amino acids by a relay of bacteria known as the ammonifying bacteria. The ammonia is then oxidized by another group of bacteria, forming nitrites (NO_2). The nitrites are oxidized to nitrates (NO_3) by a third group of bacteria. The activities of the various bacteria are essential in providing an available nitrogen supply for all higher plants, which, apparently, can take up nitrogen only in the form of nitrates. Indirectly this bacterial action is also the source of the nitrogen supply for all animal life.

Since ammonia escapes rapidly into the air, and nitrates, being soluble in water, are readily leached out of the soil and carried into the streams, one of the problems of the farmer is to maintain an adequate supply of nitrogen in the soil. Chemists have developed methods whereby the free nitrogen of the air can be combined with certain other substances by means of an electric spark to form nitrogenous compounds that may be used in fertilizers. Fixation of nitrogen has been carried on very successfully and economically by **nodule bac-**

teria, so called because they infect the roots of plants, which then grow vigorously, forming globular masses or **nodules.** Although the nodule bacteria invade some other species, their association with members of the legume family (bean, pea, clover, and soybean) is best known. These bacteria get food from the cells of their host, and from the air they take free nitrogen, which is used in synthesiz-

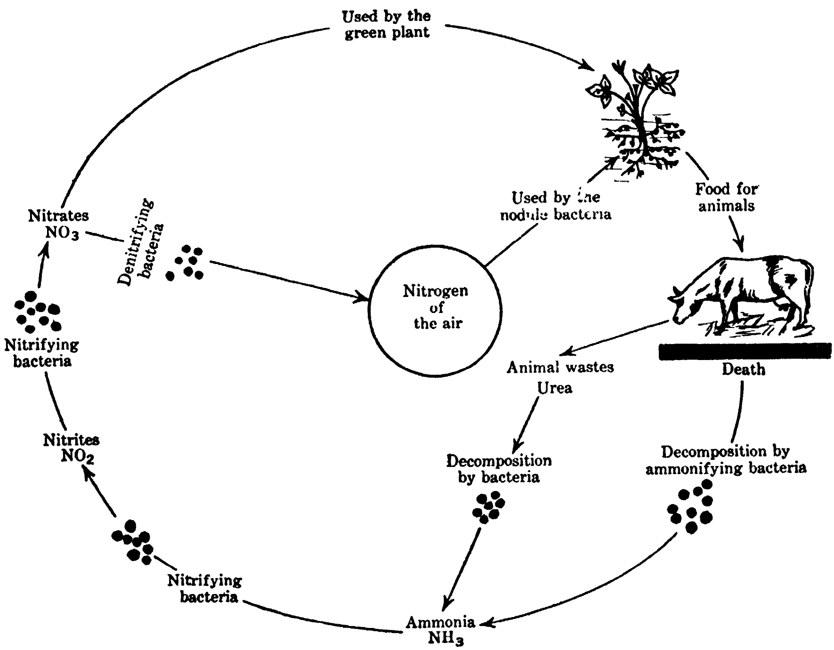


FIG. 98. Diagram of the nitrogen cycle.

ing proteins. In some way not yet fully understood these organisms make nitrogen available to the host.

It is thought that certain other organisms, including bacteria, fungi, and blue-green algae, may function in this same way. It is possible that the work of nitrogen fixation may be carried on in many of the lower forms of plant life where it has not yet been discovered.

The nitrifying organisms thrive best in a well-aerated soil with a medium moisture supply and a temperature of approximately 30° C. The conditions of high fertility, then, are identical with those that most favor nitrification. When the opposite conditions prevail—poor aeration, excess water, low soil temperature, and acid soil with abundant organic matter—**denitrifying organisms** thrive and multiply. These organisms reduce the nitrites and nitrates, liberating free

nitrogen which escapes from the soil. Here the addition of manure or other organic matter such as a commercial fertilizer would be useless, for the denitrifying bacteria present would disintegrate the added nitrogenous materials and merely increase the amount of nitrogen lost. Good drainage must be provided before such soils can be made productive.

In the plant, the nitrogen of the nitrates obtained from the soil is combined with carbohydrates to form amino acids, the building stones used in the synthesis of proteins found in protoplasm. When proteins are broken down by the metabolic activity of animals, nitrogenous wastes such as urea are formed. The wastes are attacked by bacteria, and, as in decay, the nitrogen is returned to the soil in the form of nitrates. Thus we see that nitrogen functions through the **nitrogen cycle** (Fig. 98) like carbon through the carbon cycle. For a proper appreciation of some of the most fundamental biological processes, the importance of these cycles can hardly be overestimated. Were it not for the sequence of events in these cycles, the clock of life would have run down millions of years ago.

SUMMARY

Wastes are compounds, formed in the life processes of organisms, that have no further part in the metabolism of the cells. In plants the wastes are eliminated or stored in some out-of-the-way place. They include such substances as carbon dioxide, essential oils, gums, resins, organic acids, and pigments of various kinds. Although transpiration is not a true excretory function, it is included here because it represents the elimination of excess water from the plant. In animals, wastes from the large intestine are voided through the anus. Excretions such as carbon dioxide and water, the products of carbohydrate, fat, and some protein decomposition, are eliminated through the skin, lungs, and kidneys. The decomposition products of protein metabolism, which are mostly nitrogenous, as well as water and salts, are excreted by the kidneys in the form of urine. The liver discharges some excretory products into the intestine.

Bacteria and fungi play an all-important role in the disintegration of dead bodies and the decomposition of organic compounds. Through the agency of these organisms, carbon dioxide is returned to the atmosphere, where it is again available for photosynthesis, and nitrogen is oxidized to form nitrates which can be taken up by the roots of plants to supply nitrogen for the synthesis of amino acids and proteins. Thus we see there is real biological significance in the statement, "Dust thou art, and unto dust shalt thou return."

CHAPTER VIII

HOW DO PLANTS AND ANIMALS ADJUST THEMSELVES TO THEIR ENVIRONMENT? CHEMICAL COORDINATION

Irritability has been mentioned as one of the characteristics of living protoplasm, and therefore it must be an attribute of all living things. Irritability is the capacity of protoplasm and of organisms to respond to environmental influences or stimuli. A **stimulus** has been defined as any change of relation between an organism and its environment, or between different parts of an organism, which brings about a modification in the activities or behavior of the organism, called the **response.** It is by such responses that organisms adjust themselves to the constantly changing environment in which they live. We shall use the term **adjustment** to designate the many ways in which plants and animals respond to conditions and changes in their environment. The most obvious adjustments made by organisms are the changes of location or position, such as the turning of a leaf, or the flight of a moth, toward the light. Other extremely important adjustments, such as the secretion of digestive fluid by a gland as a response to the influence of food, are more obscure and less easily noticed by the casual observer.

In using the term environment we must think not only of the external factors that influence a plant or animal but also of the internal conditions likewise capable of inducing reactions within the organism. Each individual cell, whether a unicellular organism or some unit of a multicellular organism, has its own environment. Since irritability is a property of all living protoplasm, it follows that each unit of this substance is irritable, and consequently every living cell makes its own adjustments in the performance of its functions.

In any machine made up of many parts, the working of the parts must be so coordinated that each one contributes to the smooth operation of the machine. In fact, coordination is the fundamental principle underlying all organization. In a football team each player

has his particular assignments, but they are so correlated in the various plays that when they are executed successfully the eleven men function as a team, a unit, and not as eleven independent individuals. The same principle underlies the organization of every plant and animal. Although each cell responds to its own particular environment, the activities of all the cells and groups of cells (tissues and organs) are so regulated and correlated by coordinating agencies that, like the individual performances of the members of an orchestra, they merge and blend into a perfect harmony.

In the living organism two agencies operate to bring about the correlation of activities of the component cells, tissues, and organs. These agencies are the mechanism of **chemical coordination** and the mechanism of **nervous coordination.** Apparently, the first of these two systems is the more primitive, and, in this chapter, we shall confine our attention to the subject of chemical coordination.

In chemical correlation, some part of an organism may produce a chemical substance which may exert a marked influence on the activity of another part of the same organism. These chemical agents may be effective in the cells in which they are produced, or they may diffuse through the cell membranes and be transported to other parts of the organism by the blood, lymph, and tissue fluids. Such chemical factors differ widely in nature, exert different influences, and determine and control different cell responses—in brief, they aid in coordinating the functions of the different units of the organism. The maintenance of this relationship among component parts existing in both animals and plants is known as **chemical coordination.**

CHEMICAL COORDINATION IN ANIMALS

We have already seen that the body has certain glands whose secretions leave the gland by way of a duct. In addition to these glands there are other secreting organs without ducts whose secretions are poured directly into the blood stream, which carries them to the various tissues of the organism. Such glands are known as **ductless** or **endocrine glands** (*endon*—within; *krino*—I separate), or organs of **internal secretion** (Fig. 99). The following statement of Hoskins gives some idea of the importance of these glands, "The evidence is now conclusive that what we are—physically, mentally, sexually and emotionally—depends in no small measure upon the functions of our endocrine glands."

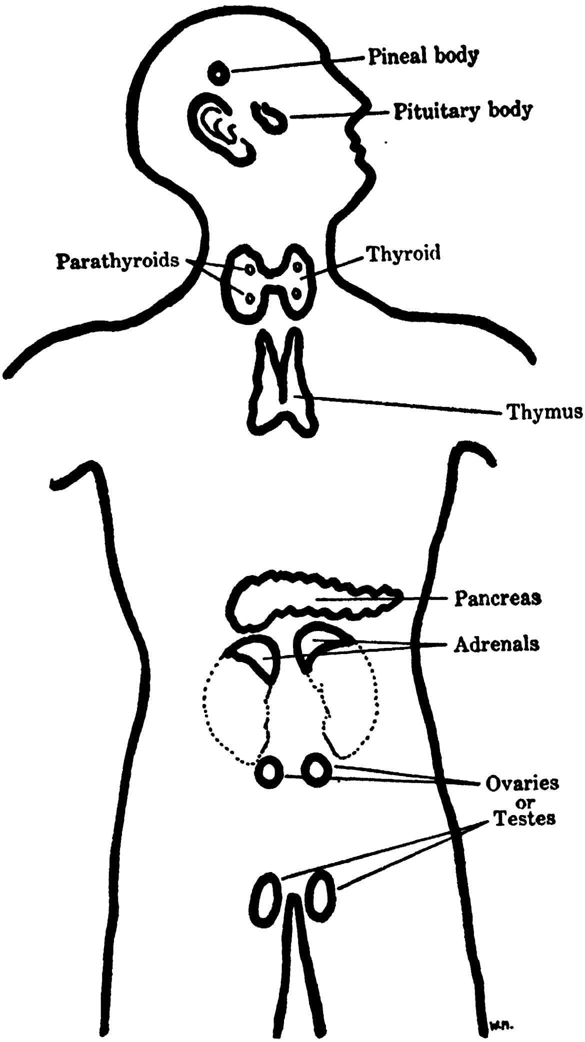


FIG. 99. Diagram showing location of endocrine glands.

HORMONES

The internal secretion of the endocrine glands is known as a **hormone** (*hormao*—I arouse). Hormones are agents of chemical coordination; they are usually excitatory and specific in their actions. They, together with the nervous system, integrate all the activities of most animals. Perhaps the best picture of hormone action can be presented by describing the functioning of one of these secretions.

We have already seen that food is acted on by the pancreatic juice in the small intestines. Some organs are aroused to secrete through nervous stimulation, and for a long time the pancreas was thought to be such an organ. However, about 1902, Bayliss and Starling found that, when food passes into the small intestine, certain intestinal glands pour a substance into the blood stream called **secretin.** In a few seconds the secretin is carried by the blood to the pancreas, which at once begins to secrete pancreatic juice. Thus it was found that the secretion of the pancreas is initiated not by nervous impulse but by the stimulation caused by a chemical substance (secretin), a hormone. There is no conclusive evidence as to how these hormones function, but it is thought that they act as catalysts. Hormones are found not only in animals but also in plants.

Hormones are relatively simple compounds but very powerful physiological agents. The summary of a statement by Hoskins brings this out quite vividly. Epinephrin, the active principle of the adrenal medulla, can be readily detected by biological assay in a dilution of 1 part in 300,000,000. In other words, if 1 ounce of this substance were so diluted with water, the diluted solution would fill 9 miles of gasoline trucks apportioned 268 trucks to the mile, and each truck holding 2,000 gallons Abel has isolated from the pituitary gland a hormone so powerful that 1,560 miles of such trucks would be required to reduce 1 ounce to the undetectable point.

The pancreas and the islets of Langerhans. It had long been suspected that the pancreas was involved in diabetes, an ailment in which the sugar of the blood is lost in the kidneys and voided with the urine. For example, it was observed that ants which feed on sugar were attracted to the urine of dogs whose pancreases had been removed. After years of experimentation Dr. Banting, a Canadian doctor, assisted by several co-workers, finally demonstrated the relation between the pancreas and diabetes. In his experimental work, Banting tied off the pancreatic duct of a dog, thus causing the cells secreting the digestive pancreatic juice to degenerate. He discovered that certain isolated areas, made up of a different kind of cells and called, after the discoverer, islets of Langerhans, were apparently not affected by this tying off of the pancreatic duct, nor was there any evidence of diabetes. He then removed the entire pancreas from another dog, which soon developed diabetes and died. Now this diabetic condition could have been the result of various factors and events incident to the operation, such as the effect of the anesthetic, the rearrangement of tissues, hemorrhages, and like operative disturbances. To eliminate the influences of such factors, a controlled

experiment was set up. The same operation was performed upon another dog except that the pancreas was not removed. This dog did not develop diabetes. Evidently the lack of the pancreas was responsible for the disease.

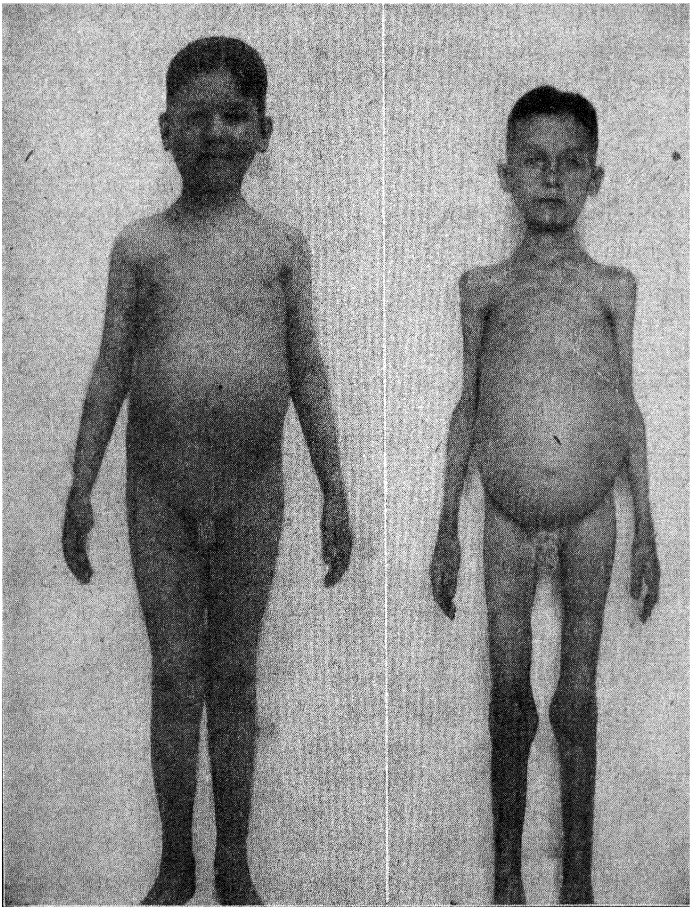


FIG. 100. Effect of insulin. *Right,* August 20, 1922, before insulin treatment. *Left,* June 20, 1923, ten months after insulin treatment. *By permission of Dr. Frederick M. Allen and the Journal of the American Medical Association.*

The entire pancreas was extracted and the extract was injected into a diabetic dog whose pancreas had been removed. It was discovered that the extract did not change the condition of the dog. Apparently enzymes of the pancreatic juice destroyed the diabetes-preventing substance.

Meantime Dr. Banting remembered that in embryonic dogs the islet tissue developed earlier than the cells secreting pancreatic juice. So he made an extract from the embryonic pancreas, and injected this into the tissues of a depancreatinized dog dying of diabetes. The dog's blood sugar increased, and in a few days the animal had recovered and was apparently normal. Work on the preparation of a diabetes-preventing extract continued, and finally a carefully prepared extract was tried on a man afflicted with diabetes. It worked! Today, this hormone called **insulin** (*insula*—island) is used as a standard treatment of diabetes, and thus another dread malady has been conquered (Fig. 100). However, since it does not restore the lost function to the islets of Langerhans, insulin must be given throughout life. Continued biochemical research has now made it possible to use purified extract of insulin from pancreatic tissues of cattle and other domestic animals. Moreover, we see once more that this important discovery was not achieved "overnight" but only after years of careful, scientific experimentation.

The thyroid and thyroxin. Thyroxin is an extract of the endocrine gland, the **thyroid,** a two-lobed organ located adjacent to the windpipe, just below the voice box or "Adam's apple" (Fig. 99). For many years, in various Alpine valleys and in the Pyrenees, there lived dwarflike human beings who were only three or four feet tall. The arms and legs of these people were unusually short, and their short legs were so bowed that their walk was an ungainly waddle. The coarse and leathery skin hung in folds in various parts of the body. The teeth were defective, and the hair was sparse and coarse. Not only were their heads misshapen and the tongues entirely too large for their mouths, but also their minds were those of children. This condition was called **cretinism.** About 1891, Dr. Murray tried injecting under the skin of some of these unfortunates an extract of thyroid made from the glands of another animal. The results were positively astounding! Many children in this cretin condition when thus treated soon became practically normal and remained so as long as the treatment was continued (Fig. 101).

Interesting results of experiments on other animals were obtained from the use of this new extract. Gudernatsch found that frog tadpoles fed dried thyroid matured much earlier. They soon developed legs, lost their tails, and became tiny frogs not much larger than a fly. Later Allen found that, if he removed the thyroids of a frog tadpole, it always remained a tadpole, but became abnormally large. When fed thyroxin it changed into a frog. Other very interesting

facts have been discovered about the effects of thyroid extract on other animals.

The thyroid gland regulates the oxidative rate in the animal, that is, heat production and energy liberation in all the organ systems. If thyroid secretion is either deficient or too abundant, abnormal mental and physical effects may be produced. Undersecretion of the thyroid lowers the rate of metabolism and causes the individual

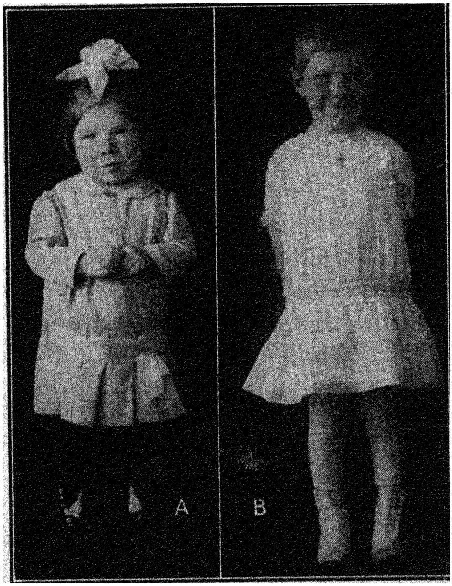


FIG. 101. Effect of thyroxin. *A,* cretinism before treatment. *B,* after treatment with thyroxin. *Photographs furnished by Dr. Edwin C. Kendall.*

to become fat, sluggish in mental reactions, and even feebleminded. The heart rate is lower and the sex drive decreased. A condition somewhat similar to cretinism may appear in adults affected with subnormal thyroid glands, but the degree of cretinism is modified by the age of the individual. Thyroid deficiency may stimulate the formation of new gland tissue, resulting in an enlargement of the thyroid known as **simple goiter.** This is a compensatory reaction. When one of a pair of organs such as the kidneys, or part of an organ, is destroyed, the remaining tissue may enlarge or increase its activity to "compensate" for the loss.

On the other hand, if, for some unknown cause, the thyroid is overactive, the symptoms are almost the opposite of those described for thyroid insufficiency. The basal metabolic rate is increased, which

calls for more and more food. The individual becomes highly nervous—overactive, so to speak—and irritable. Sometimes a complete derangement follows and **exophthalmic goiter** may develop, characterized by bulging eyeballs, irregular heart action, nervousness, and insomnia.

Man has been able to overcome simple goiter and cretinism. He now knows the chemical nature of thyroxin, which is really an amino acid ($C_{15}H_{11}O_4NI_4$) now prepared synthetically by the biochemist. Thyroxin is rich in iodine, of which the thyroid gland must have an adequate supply. A study made of the distribution of simple goiter and cretinism showed that in certain goiter belts 25–60 per cent of the population was affected. These belts were usually in former glaciated regions in which the soil has been leached of its iodine, resulting in iodine deficiency in the soil, water, and plants. Such regions are the Great Lakes country and the St. Lawrence valley in North America, the Andean plateau in South America, and the Alps, Pyrenees, and Carpathian mountain regions in Europe. On the other hand, people living near the sea, where there is an abundance of salts, particularly those containing iodine, are free from goiter. This knowledge suggested the administration of iodine as a remedy for simple goiter, a treatment which has proved largely effective. Advanced cases of goiter, however, require operative treatment.

The parathyroids (*para*—near; thyroid). In man there are usually four parathyroids. They are about the size of peas and are either imbedded in the thyroid glands or located close to them (Fig. 99). In many of the early operations for goiter, after removal of the excess thyroid tissue, the patients were afflicted with twitchings, nervousness, and facial spasms. Later it was found that experimental removal of the thyroid of dogs caused a convulsive disorder called **tetany.** This begins by spasmodic contractions of the muscles leading to convulsions. There is acceleration of the heart beat, and finally death by asphyxiation owing to a spasm of the muscles which close the glottis. An examination of the blood of these animals shows a marked decrease in calcium content. Later, it was discovered that these reactions did not occur if the parathyroids were left intact within the animal.

Today it is known that the parathyroids secrete a hormone, **parathormone,** which regulates the calcium level in the blood, which, in turn, is responsible for normal muscle function, bone growth, and tooth formation. The hormone is destroyed by digestion; consequently in parathyroid deficiency the hormone must be injected. The

effects of parathyroid deficiency can also be remedied by the injection or feeding of calcium.

An oversecretion of parathormone causes the calcium and phosphorus to leave the bones and the teeth; carried away by the blood, these elements are lost through the kidneys. The bones become soft, and deformities often result. We have already seen that vitamin D, the antirachitic vitamin, is concerned with calcium metabolism. Apparently, however, there is little connection between the vitamin mechanism and the hormone function. In chronic lead poisoning parathormone extracts have been used to remove lead deposits from the bones. Parathyroid extracts have proved effective in the treatment of children suffering from chronic convulsions, irrationalism, maniac excitation, and similar disorders.

The pineal body. In man this gland, about the size of a pea, is located on the dorsal surface of the brain between the cerebral hemispheres (Fig 99). The philosopher Descartes thought that it was the seat of the soul! At the present time, finding little evidence of an endocrine function, many scientists are of the opinion that the pineal body is not an endocrine gland.

The thymus gland. This glandular structure is very prominent in young animals. In man, it lies behind the upper part of the breastbone and extends from the heart up into the neck (Fig. 99). It practically disappears in the adult. Like the pineal gland, it is the subject of many conflicting reports and opinions. The suggestion has been made that it speeds up growth and that it produces lymphocytes, a non-endocrine function. On the other hand Rowntree and his associates report that, in a series of experiments on white rats, repeated injections of an extract of the thymus over several generations resulted in the formation of a strain of precocious rats. These rats produced young rats whose eyes were open at birth and which developed fur more than ten times as soon as the control rats. Teeth erupted at birth instead of ten days later, and sexual maturity was reached much earlier than usual. Some attempts to repeat these experiments have failed. Carlson and Johnson conclude that "at present the weight of the evidence seems to be against the hormone interpretation, although the final answer must wait further experimentation."

The preceding discussions of the function of the pineal and thymus are good illustrations of the workings of science. A number of years ago, these glands were considered to be unquestionably endocrine in function. Further experimentation, as well as a more critical repetition of former experiments, have caused earlier conclusions to be

scrapped and have reduced the problem to the "I do not know" status. Someone has well said that the path of science is strewn with the wrecks of dead and dying theories. A scientist must have an open mind and be willing and able to adjust or scrap his previous conclusions in the light of new evidence.

The adrenal glands (*ad*—near; *renes*—kidney). In most vertebrates these glands lie close to the kidneys, and in man they cover the anterior ends of the kidneys like little caps (Fig. 99). An adrenal gland is made up of two distinct regions which have had an entirely different embryological origin. The outer part of the gland is known as the **cortex** and the center as the **medulla.**

The secretion of the medullary region of the adrenal gland is called **adrenalin** or **epinephrin.** The chemist has analyzed adrenalin ($C_9H_{13}O_3N$) and is now able to prepare it synthetically in the laboratory. Unlike most endocrine glands, the medulla is under nervous control. It regulates blood pressure and the tonus of the involuntary muscles. A lack of adrenalin may cause a loss of strength or "nerve." When adrenalin is injected the heart beat increases, the arteries contract, the hair bristles, the skin becomes "gooseflesh," and the eyeballs tend to protrude and the pupils dilate. Cannon and his co-workers believed that the reactions associated with fear or anger may be caused by an increased secretion of adrenalin into the blood stream, brought about by nervous stimulation. Apparently the function of the medulla can be taken over by the autonomic nervous system, for the medulla can be removed without affecting the life processes of the animal.

Since adrenalin causes the dilatation of the bronchioles of the lungs, it is used for the relief of asthma and hay fever. It is applied locally to prevent excessive bleeding from wounds. Sometimes adrenalin has been injected directly into the heart after it has stopped beating, to initiate renewed contractions and thus restore life.

The cortex secretes the hormone **cortin,** which seems to be essential for life since removal of the cortex results in death. When the adrenal glands are removed from experimental animals, water and sodium chloride are lost from the blood and tissues, and the basal metabolic rate decreases. The animals lose their appetite. Muscular weakness ensues, ending in prostration and death. Destruction of the adrenal cortex in man by Addison's disease causes many of the effects just listed, and, in addition, the skin becomes a peculiar bronze color. Injections of cortin alleviate these conditions and sometimes there is complete recovery.

Tumors in the cortex have resulted in abnormal and precocious sexual maturity; in women, overactivity of the cortex may result in a change toward masculinity. Some cases have been recorded where an almost complete sex reversal has taken place. According to Hoskins, "the deep-voiced, coarse-featured, bearded ladies of the circus sideshows are probably victims of this glandular mishap"

FIG. 102. Bearded lady, probably the result of some disturbance in the adrenal cortex. *Copyrighted by Underwood and Underwood, New York. Reproduced by permission.*

(Fig. 102). There is conclusive evidence of an interrelation between the pituitary gland and the cortex of the adrenal.

The gonads and their hormones. It has been known for a long time that the ovaries of the female and the testes of the male produce eggs and spermatozoa, respectively (Fig. 99). More recently it was discovered that these glands also produce hormones. In the ovaries the egg develops in a fluid-filled vesicle called the **Graafian follicle,** which apparently is the source of the hormone called **estrin** (*oistros*—gadfly, frenzy) or **theelin** ($C_{18}H_{22}O_2$). Among other effects, estrin controls the recovery changes in the wall of the uterus succeeding the menstrual period up to the final stage of preparation when the hormone in the **corpus luteum, progestin** or **progesterone,** becomes active. The corpus luteum is a yellow, cellular mass which replaces the Graafian follicle after it has burst to release the egg

from the ovary. Progestin controls the final changes in the uterine wall and helps to bring about the implantation of the embryo in the uterus. It also helps govern the formation of the **placenta,** the organ of nutrition for the developing embryo and fetus. Although both estrin and progesterone play an essential role in the growth of the nipples, ducts, and secreting portions of the mammary gland, it remains for a specific hormone from the pituitary gland to bring about lactation or secretion of milk. The process of human reproduction will be described in a subsequent chapter, and the action of these hormones and their effect in the human female reproductive cycle will be more fully discussed.

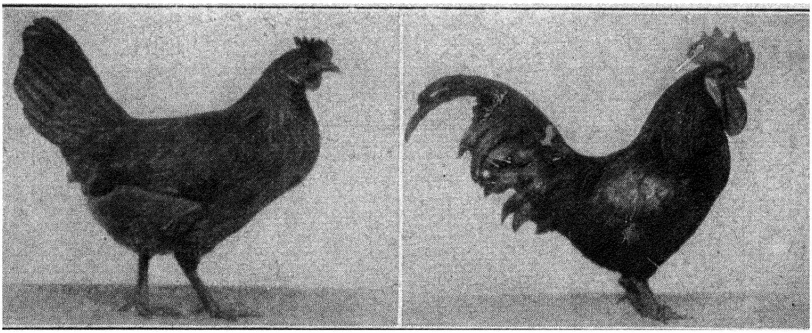
Estrin is also responsible for the production of **secondary sexual characters** of the female such as the accessory reproductive organs. In female birds the type of plumage and the lack of combs and spurs are the result of the influence of estrin. Estrin influences the psychic or behavior reactions of the female in man as well as in birds. If the ovary is removed and, later, estrin is injected, the female's physical and behavior characteristics remain normal. When such diseases as cancers and tumors of the genital organs of women make operations necessary, if at all possible, one ovary or some ovarian tissue is not removed.

The hormone of the testis is known as **testosterone** ($C_{19}H_{30}O_2$). It has been synthesized in the chemist's laboratory from cholesterol, a substance present in almost all animal tissues. It is interesting to note that most of the gonadal hormones are sterol derivatives. This hormone is secreted by tissue of the testis other than that which develops into gametes. The hormone is responsible for the formation of the secondary sexual structures of the male such as the accessory reproductive organs and, in man, the deep voice and distribution of hair. In the males of many varieties of chickens, this hormone induces the development of the comb and spurs. The psychic or behavior patterns peculiar to the male of all animals are evidently influenced by this hormone.

The following experiments have definitely shown that many specific physical and mental characteristics associated with sex are dependent upon the secretions of the gonads. For instance, if the ovary of a female guinea pig is transplanted into a male from which the testes have been removed, the hair and the skeleton of this male come to resemble those of the female and the milk glands enlarge to functional size. Again, if the ovary is removed from a young leghorn hen, she will develop a larger comb, spurs, and wattles, because in birds there is but one functional ovary and when it is removed

the other, functionless gonad develops into a testis which produces the male hormone responsible for these characteristics. The plumage will become male-like owing to the absence of the female hormone (Fig. 103).

Castration and **ovariectomy** (removal of the ovaries) are regularly practiced by livestock growers and poultrymen. The unsexed animals are usually more docile, develop larger bodies, and take on fat more rapidly. Castrated (testes removed) roosters are known as



A *B*

FIG. 103. Sex reversal in a chicken. *A,* hen before operation. *B,* the same bird after operation showing the change from female to male characteristics. *By permission of Dr. L. V. Domm.*

capons, pigs as barrows, horses as geldings, bulls as steers, and men as eunuchs.

For a long time it has been known to livestock breeders that if, when twin calves are born, the one calf is a male and the other a female, the female will be sterile. The sterile female is known as a "freemartin." Lillie, in his study of the problem, showed that the sterility was caused by the fusing of the fetal membranes so that there was a mixture of the male's blood and its hormones with that of the female. Since the male gonads develop more rapidly, the male hormone is being secreted into the circulation for some time before the hormones of the ovary are produced. As a result the female has some male characteristics as well as female and is known as an **intersex.** When frog tadpoles of different sexes are grafted together in pairs, the same result occurs.

One of the most interesting and clever experiments performed in endocrine research was the following: A portion of the uterine wall of an animal was removed and placed in the anterior chamber of the eye of the same animal, and it grew! There were no nerve connections, therefore any change taking place

there would have to be brought about by chemicals carried to it by the blood stream. This uterine tissue was found to exhibit the same cycle of changes as those taking place in the walls of the uterus. In monkeys, even the bleeding which occurs in normal uterine tissue at menstruation was observed. The changes which take place in the uterine mucosa as a result of the injection of hormone extracts could be readily observed in the transplant.

The pituitary body. This gland is attached to the midregion of the lower surface of the brain and rests, well protected, in a small cavity in the floor of the skull. In man, it weighs about $\frac{3}{140}$ of an ounce and is about the size of a hazelnut. This gland exerts so much control over the various body functions that it has been called "the master gland" of the body. It secretes a multiplicity of hormones, but no "pure crystalline hormone has as yet been isolated."

The pituitary gland is made up mainly of two lobes of different embryological origin. The anterior lobe arises from a pouch pinched off from the roof of the mouth, and the posterior lobe is derived from the floor of the brain. The two lobes are united and attached to the brain by a stalk (Fig. 99). Each lobe of the gland has its own peculiar secretions.

The various extracts from the posterior lobe have the general name of **pituitrin.** Abel reports that the chemical salt of the hormone extracted from the posterior lobe is so powerful that a dilution of 1 part in 15,000,000,000 produces a noticeable effect in the uterine muscles of a female guinea pig. The extract of the posterior lobe (Fig. 99) is made up of two hormones: one tends to raise the arterial blood pressure; the other is a powerful stimulant of the uterine muscles and is used by physicians to hasten childbirth. According to some physiologists, pituitrin acts more like a drug than a hormone.

According to Gortner * the anterior lobe of the pituitary "produces no less than eleven different hormones, all but one of which may be regarded as exerting some specific effects. More than half of these may perhaps be regarded as 'master' hormones, in that they exert specific control either over other endocrine glands or over the production or secretion of other hormones!"

Certain hormones from the anterior lobe influence growth. Rats treated with extract of the anterior lobe have grown to more than *twice* the size of their litter mates. Apparently the same growth effect is produced in man, for, if the gland is enlarged and overactive, giants result (Fig. 104). Goliath, the Philistine, and overlarge individuals of our own times may have had enlarged pituitaries from

* Ross A. Gortner, *Outlines of Biochemistry*, second edition, p. 851, John Wiley & Sons, New York, 1938.

FIG. 104. Extremes in size of the human body, probably the result of abnormal functioning of the pituitary gland. The giant, 8 feet, 9 inches, in height, may be the result of an overactive pituitary; the dwarf by his side may be the result of an abnormally inactive pituitary. The woman is of average size. *Copyrighted by Underwood and Underwood, New York. Reproduced by permission.*

childhood. Autopsies of many of these "giants" have shown enlarged and tumorous pituitaries. Sometimes the gland does not begin excessive secretion until after maturity is reached, and then, instead of giants, gorillalike men with huge hands and feet, enlarged heads, enlarged bony ridges over the eyes, and protruding lower jaws and tongues are the result. This condition is called **acromegaly** (*akron*—extremity; *mega*—large).

Deficiency of this secretion results in normally proportioned, dwarflike men (Fig. 104). Tom Thumb and other midgets of the circus probably owed their livelihood to the subnormal activity of the anterior lobe of the pituitary. Investigators have found by experimentation that removal of the pituitary in dogs and rats results in retarded growth and development which can be prevented by implanting pieces of fresh pituitary under the skin. If such implants are made on normal rats, gigantism results.

Another hormone of the pituitary affects the functioning of the gonads. If the gland is removed before puberty the gonads never mature. If the operation is performed on adult animals, production of eggs and spermatozoa ceases, and changes take place in the sexual cycles of the female. On the other hand, excess amounts of the hormone hasten the breeding period and the maturing of eggs and spermatozoa. If some of this gland is transplanted under their skin, frogs, which normally breed once a year in early spring, may be stimulated to lay eggs within a week or ten days.

Recent research has shown that there is a close interaction between the hormones of the anterior lobe and those of the ovary. The pituitary secretes a hormone called the **follicle-stimulating hormone (F. S. H.),** which causes the production of estrin. Another pituitary hormone, known as the **luteinizing hormone (L. H.),** acts on the corpus luteum to bring about the secretion of progestin, which in turn acts on the mucosa lining the uterus (Figs. 105 and 170).

Another anterior-lobe hormone, **prolactin,** apparently stimulates the mammary gland to secrete milk. Removal of the pituitary from lactating rats causes the flow of milk to cease, whereas injection of prolactin causes the animal to lactate. Injection of prolactin into virgin rats stimulates the mothering instinct, and such rats will build nests.

Evidence has accumulated which indicates that there is a close relationship between the thyroid and the pituitary. Remove the pituitary, and the animal shows a condition of hypothyroidism; inject the extract of the pituitary into a normal animal, and hyperthyroidism results. This action seems to be independent of the

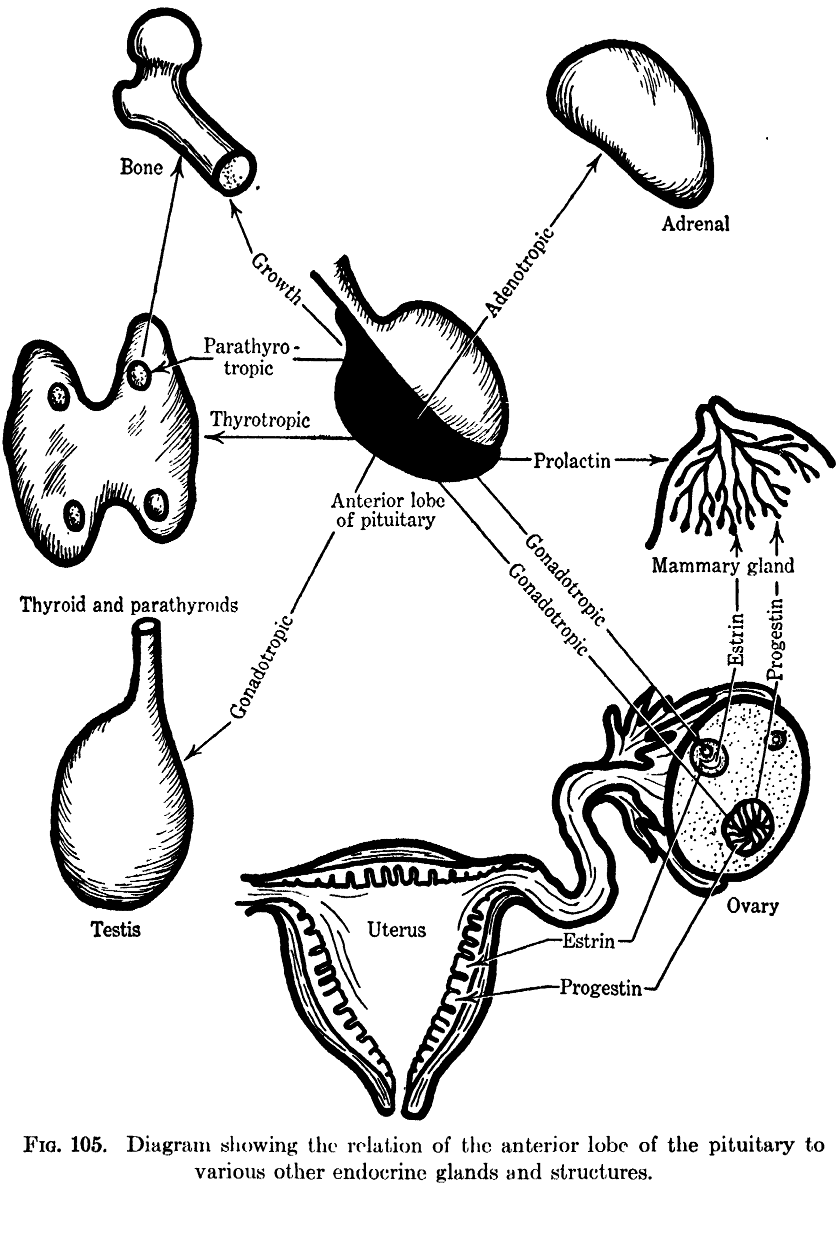


FIG. 105. Diagram showing the relation of the anterior lobe of the pituitary to various other endocrine glands and structures.

thyroid. The pituitary apparently exerts physiological effects on the adrenal cortex and on the parathyroids. Others of its hormones seem to have some control over insulin production in the pancreas. The pituitary is truly the "headquarters of the endocrine system" (Fig. 105).

Other hormones of vertebrates. We have already pointed out that secretin, a substance secreted by the intestine, is a hormone. There is some evidence that the walls of the stomach may secrete a hormonelike substance called **gastrin** and that certain liver extracts may act like hormones. It has been shown that when fatty foods enter the duodenum the intestinal wall forms the hormone **cholecystokinin,** which, carried by the blood to the liver, causes the gall bladder to contract forcibly, sending the bile into the intestine. The placenta, a structure developed in the higher mammals, secretes a hormone resembling one of those produced by the anterior lobe of the pituitary. It may also secrete estrin. The Aschheim-Zondek test for pregnancy in women is based upon the presence or absence in the urine of the first-mentioned hormone, the "pituitary-like" one.

Hormones of invertebrates. The arthropod *Dixippus* has a gland in the head which secretes a pigment-activating hormone responsible for the coloring of the animal. Hanström found in the head of certain insects a substance which, if injected into shrimps, tends to concentrate their red and yellow pigments. Destruction of certain gonadal tissue in some crabs often results in partial sex reversal somewhat similar to the phenomenon observed in female chickens when the ovary is removed. In certain arthropods there is some evidence that both metamorphosis and molting are controlled by hormones. In the bug *Rhodnius* the hormone controlling molting seems to be secreted by glands located in the head.

Other Chemical Correlations

There is some evidence that the pyloric valve is more or less chemically controlled. The acid food when it touches the intestinal walls may cause a tightening of the valve muscles. When the alkaline bile and pancreatic juice gradually neutralize the acid food in the intestine the valve muscles relax, only to contract again when more acid food from the stomach strikes the intestinal walls. However, this does not fully explain the valvular action.

We have already pointed out that the amount of carbon dioxide in the blood controls the respiratory center in the brain and is thus the regulator of breathing movements. The force and rate of the heart beat both directly and indirectly are to some extent under the control of carbon dioxide.

Neurohumeralism. A few years ago Loewi, a German, removed the living beating hearts from two anesthesized frogs and so connected them that an artificial fluid (Ringer's solution) would flow through both hearts. He then stimulated the vagus nerve (part of the autonomic system) of *only one heart* and slowed down its beat. The other heart, though it had no nervous connection, was similarly affected by something in the circulating liquid. Continued experimentation and investigation have shown that there was given off, by the stimulated vagus nerve endings, a substance called **acetylcholine,** which acts on the cardiac muscle as an inhibitor. This inhibitory substance is given off by the **craniosacral autonomic system.** Another substance, **sympathin,** liberated by the nerve endings of the **thoracolumbar system,** acts as an accelerator. Sympathin is similar to adrenalin in its effect on muscles. Interestingly enough, the adrenal medulla and the autonomic system have the same common embryological origin. Apparently, the nervous effects of the autonomic nervous system "are not brought about by the nerve impulses themselves, but by chemical substances which the impulses cause to be liberated from the nerve endings." Recently it has been shown that the contraction of skeletal muscle (voluntary) is caused by the liberation of acetylcholine from the voluntary motor nerve endings. These discoveries may lead to research which may revolutionize our concepts of the nervous mechanism. In that event we shall be throwing aside or modifying old theories and hypotheses in the light of new evidence.

CHEMICAL COORDINATION IN PLANTS

Within recent years the investigations of plant physiologists have revealed the presence of hormones in plants. These have been called **phytohormones** (*phyton*—plant). Just as in animals, these hormones exert their influence in parts of the organism other than those that produce them. Like animal hormones, plant hormones are physiologically effective in extremely dilute concentrations. Although the role of phytohormones is not yet fully understood, it is now believed that these substances are at least partly responsible for certain correlations among the activities of different parts of the plant.

The best-known and most intensively studied phytohormones are the **auxins.** It is now quite generally thought that elongation of the cell will take place only when auxins are present, and consequently these hormones are considered very important factors in all growth. Apparently auxins are produced mainly and perhaps solely in the apical meristematic tissues such as occur in developing leaf and flower buds, whence they are transported downward into all parts of the plant. Auxins are present in animals, but here they are not known to have any physiological significance, and their presence is explained by assuming that they are derived from plant materials eaten by the animals.

What was originally called auxin is now known to be a complex of substances, and other compounds that induce the same physiological responses are regarded by some authorities as auxins. Because of this lack of definite information about the specific effect of each one of these agents, there is much confusion concerning the inherent nature and composition of this group. Root formation on cuttings is greatly accelerated by a number of compounds when used in proper concentration, but it is thought that these agents can be effective only in the presence of auxins. Doubtless the formation of roots is influenced by many factors including auxins (Fig. 106).

In addition to auxins, one author suggests the existence of another group of plant hormones which he calls **calines.** **Rhizocaline,** produced in the aerial parts of the plant, is essential in the formation of roots. **Caulocaline,** produced in the roots, activates elongation of stems. **Phyllocaline,** probably formed in the leaves, is necessary for the growth of the leaves. It is believed that rhizocaline and caulocaline can exert their influence only in the presence of auxins. Some investigators think that flowering is induced by the action of a specific hormone called **florigen.**

The correlation of different members is readily observed in the behavior of the terminal and lateral buds of many species of plants. In each leaf axil there is a lateral bud, but these buds usually do not develop into lateral branches as long as the terminal bud remains active. However, if the terminal bud is injured or removed, one (or several) of the lateral buds immediately becomes active. This dominance of the terminal bud is very clearly demonstrated in such conifers as the spruce and pine. Here the central axis of the crown, extending well above the shorter lateral branches, is called the "leader." If the terminal bud of the "leader" is removed, one (sometimes more) of the shorter, lateral branches will grow more rapidly, assuming an erect position to become a second "leader," replacing the original one in the subsequent growth of the tree. The dominance of terminal buds inhibiting the growth of lateral buds is explained differently by different workers, but all agree that this kind of growth correlation is the result of some hormonal influence. Evidence furnished by numerous experiments seems to indicate that the initiation of cambial activity in the spring is the result of some hormonal influence. We shall see subsequently that hormones also play an important part in the growth movements of plants.

Very recently evidence has been accumulated to prove the necessary presence of a phytohormone in injured tissues to activate cell divisions. If the mutilated surface is at once rinsed with water, very few cells divide. On the other hand, if the surface of the wound is

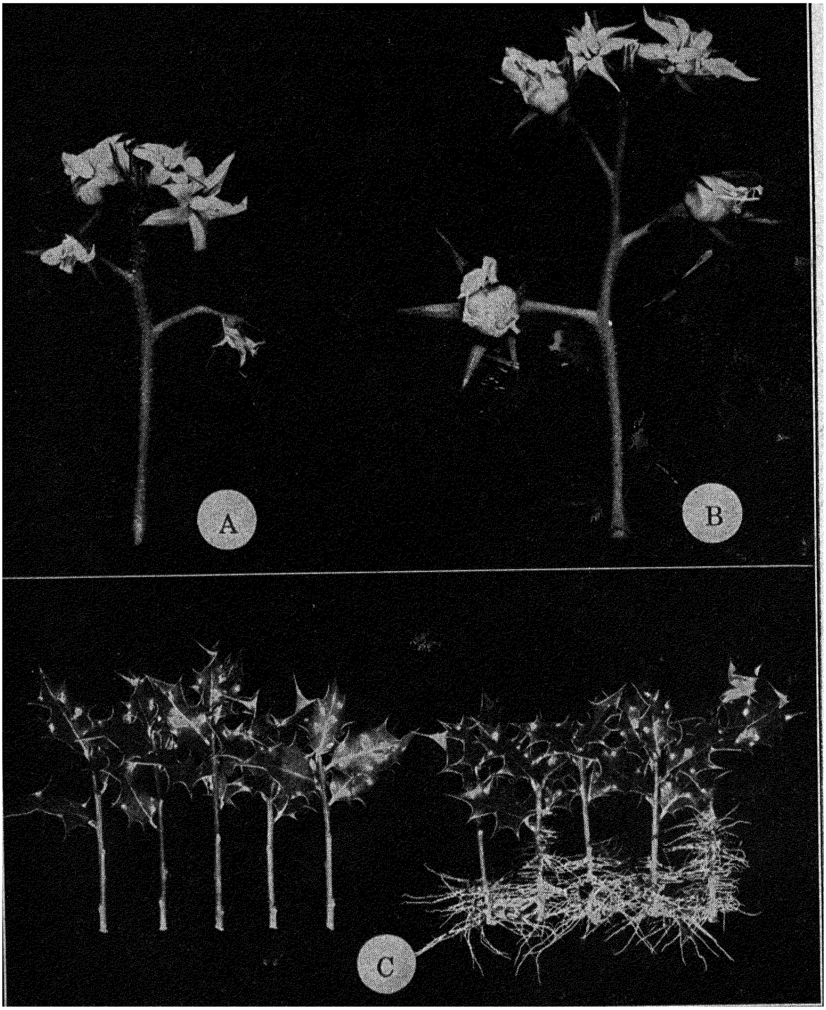


FIG. 106. *A*, cluster of tomato flowers. *B*, formation of fruits in flowers from which stamens were removed, and fruit formation was induced by auxin applied to the surface of the ovary. Fruits appear normal but lack seeds. *C*, roots induced in English holly (*Ilex*) by treating the basal end of the cuttings with auxin preparation. *Photographs furnished by P. W. Zimmerman, Boyce Thompson Institute for Plant Research.*

smeared with finely ground tissue taken from another plant of the same species, the number of cell divisions is much increased. Thus the healing of wounds in plants seems to be initiated by the influence of a "wound hormone" for which the name **traumatin** (*trauma*—wound) has been suggested.

Our knowledge of phytohormones is very fragmentary. This field of investigation is in its earliest infancy, and much work remains to be done. It is probably not too much to anticipate great developments in the future, revealing the presence in plants of hormones that bring about a chemical coordination of all the activities of the various tissues and organs found in the organism.

SUMMARY

Protoplasm being irritable and capable of response, living organisms can adjust themselves to changes in their environment. Environment of an organism includes both internal and external conditions and factors. The activities of the various parts are coordinated so that they all combine to represent the functioning of the organism as a whole. Coordination is brought about by chemical agents and in animals by a nervous system.

In animals, hormones secreted by endocrine glands are the chemical coordinating agents. Secretin activates the secretion of pancreatic juice. Insulin prevents diabetes. Thyroxin regulates the oxidative rate in the animal. Deficiency of thyroxin may result in cretinism or in simple goiter; too much thyroxin may induce exophthalmic goiter. Parathormone regulates the calcium level in the blood. Adrenalin regulates blood pressure and the tonus of involuntary muscles. Cortin is essential for life, and it may also control sexual characteristics. Gonadal hormones regulate the development and functioning of the genital organs and secondary sexual characteristics. They are likewise responsible for certain behavior patterns. The anterior lobe of the pituitary produces such a number of different hormones that it has been called the "master gland."

Evidence of other kinds of chemical control may be seen in the action of valvular mechanisms in the alimentary canal and the influence of acetycholine as an inhibitor of cardiac muscle.

Phytohormones produced in the cells of plants are coordinating agents that regulate growth and perhaps other activities. The auxins have been most studied, and their effects are best known but not completely understood.

CHAPTER IX

HOW DO PLANTS AND ANIMALS ADJUST THEMSELVES TO THEIR ENVIRONMENT? *(Continued.)* TROPISMS, NERVOUS COORDINATION, AND MOVEMENT

We have already learned that adjustment of the organism involves responses to stimuli of various kinds. According to the form of energy involved, stimuli may be classified as follows: **mechanical** (contact, pressure, sound); **thermal** (changes in temperature); **osmotic** (changes in osmotic pressure); **chemical** (changes in concentration of chemicals); **electrical** (changes in strength and direction of the electrical current); and **photic** (changes in color intensity or direction of light). The effectiveness of these stimuli depends not only on the nature and extent of the change, its rate or suddenness, but also on the physiological condition of the organism.

Responses may be easily perceptible or quite imperceptible. A response may be gradual and not easily detected, like a slow change in the rate of metabolism or in the form or structure of a cell as the result of a gradual change in pressure, temperature, or chemical composition. However, the striking, easily observed responses, the ones with which we shall be primarily concerned, are so great as to be entirely out of proportion to the stimuli. They may be likened to an explosion brought about by pulling a trigger.

Kinds of response. The kind of response depends upon the kind of effector involved and not upon the nature or magnitude of the stimulus. Thus a muscle cell (not necessarily the entire muscle) always responds by contraction, no matter what kind of stimulus is applied; and a gland cell always secretes, regardless of the stimulus affecting it. Some of the special types of responses are: **mechanical,** such as muscle contraction, ameboid movement, and turgor movements (in plants); **secretion,** the release of stored substances from a cell; **luminescence,** production of light; **color change,** contraction or expansion of pigment cells; **electrical discharge** of considerable strength. The magnitude of the response is not dependent upon the *strength* of the stimulus but upon the *condition* of the cell at the time it is stimulated. At a given time a stimulus of a certain

strength will be required to evoke a response. A weaker stimulus will have no effect, and one of greater strength will produce exactly the same response as that induced by the weakest effective stimulus so long as the condition of the cell remains the same.

A cell never makes an incomplete or partial response. If a stimulus evokes a state of excitation in any given cell, such a cell will always respond to the limit of its capacity. In other words, **a cell always responds to the limit of its capacity to any stimulus which is at all effective; there is either a complete response or none at all.** This is known as the **all-or-none law.**

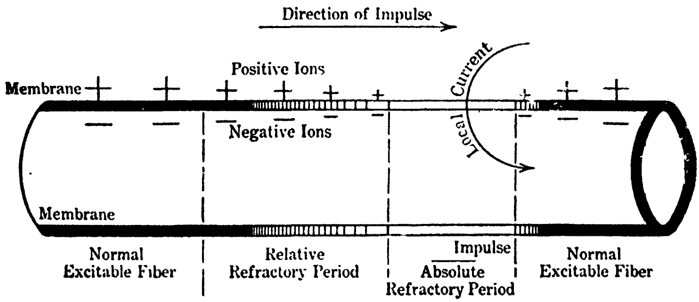


FIG. 107. Diagram showing transmission of impulse along a nerve. Note that the action current is transmitted by a succession of changes in electrical charges along the nerve. *By permission from Boring, Langfeld, and Weld, "Introduction to Psychology." By permission of John Wiley & Sons.*

The nature of response. The immediate response of protoplasm when stimulated in any way is called **excitation.** This is a physicochemical change accompanied by an alteration of the permeability of the cell membrane, which gives rise to an electric current known as the **action current** (Fig. 107). Action currents serve as stimuli to excite other cells, and in this way the primary effect of the original stimulus may be propagated from cell to cell until responses are induced in several, even remote, parts of the organism. After excitation, the cell, if not stimulated again, will return to its original condition. However, if a stimulus of any strength is applied within a brief interval after excitation and before the cell has recovered, no excitation will be effected. This period is known as the **refractory period.** A stimulus does not always induce action; sometimes it causes the cessation of some activity of the cell, an effect known as **inhibition.** This may be regarded as a prolongation of the refractory period, since the cell during this time is rendered incapable of normal excitation.

The visible response to a stimulus frequently appears in some part quite remote from that to which the stimulus was applied. In all such responses there are three stages: **reception,** or the setting up of the state of excitation at the point of contact with the stimulus; **conduction,** the movement of the wave of excitation to some other part of the organism; and the **effective response.** From the place of the application of the stimulus to the point where the effect is noted, there is a progressive movement of the action current set up by the original stimulus. This chain of reactions has been compared to a series of events beginning with the striking of a match (stimulus) that ignites (reception) a fuse of gunpowder along which a wave of combustion travels (conduction) until it reaches a keg of gunpowder and causes a violent explosion (effective response).

Specialized tissues involved in adjustment. Although irritability is a characteristic of all organisms, there is a very wide difference between plants and animals in what may be called the rapidity, intensity, and mechanisms of adjustment. The difference is less pronounced in the lower organisms, for here many of the plants and animals respond to stimuli in much the same way. In plants, to some degree, and in animals, to a very great degree, except in the very simplest forms, certain cells, tissues, and organs become highly specialized as mechanisms of adjustment. We must bear in mind that the power of locomotion is not restricted to animals alone, for many plants are motile or have motile stages at some time during their life cycle. But the cells of most plants are much restricted in their movements by their confining walls.

Tropisms. An adjustment involving the movement of an organism or some part of an organism in some direction, determined at least to some extent by the direction of the stimulus, is called a **tropism** (*tropa*—a turning). When a potted plant is placed near a window, the leaves turn toward the light. Many insects will be attracted to a light at night. These are characteristic tropisms or tropistic responses. Several kinds of tropisms are recognized; the prefix of their designations indicates the stimulus involved. The more common tropisms are:

Geotropism, reaction to gravity (*geo*—earth).
Phototropism, reaction to light (*photos*—light).
Thigmotropism, reaction to contact (*thigma*—touch).
Hydrotropism, reaction to water (*hydor*—water).
Thermotropism, reaction to heat (*therme*—heat).
Chemotropism, reaction to chemical reagents.

Electrotropism, reaction to an electric current.
Rheotropism, reaction to currents (*rheos*—stream).
Chromotropism, reaction to color (*chroma*—color).
Heliotropism, reaction to the sun (*helios*—sun).

For free motile organisms the word **taxis** is sometimes used instead of tropism, and the terms then become chemotaxis, phototaxis, rheotaxis, etc. (Fig. 108).

When a seedling begins its development, regardless of its position in the soil, the roots grow downward and the stem grows upward. The downward curvature of the root in the direction of the stimulus is spoken of as **positive geotropism,** and the upward curvature of the stem is known as **negative geotropism.** The turning of leaves toward the light is an example of **positive phototropism** (Fig. 108). When a grape tendril comes in contact with a resistant body, such as a nail or a branch of the vine, growth proceeds more rapidly on the outer side of the tendril, causing it to coil about the object. Since the curvature is a response to contact, the reaction is called **thigmotropism.** In each of these tropisms the curvature noted is the direct result of an unequal growth of the cells on the opposite sides of the organ concerned.

An organism such as the ameba, that can move freely in any direction, exhibits similar tropistic reactions. When touched at some point with a glass rod the ameba exhibits **negative thigmotropism;** i.e., it moves away from the rod. On the other hand, if it comes in contact with a solid body and remains in close contact with it, it may be exhibiting **positive thigmotropism,** or **positive chemotropism** if the substance is food. Amebas are **negatively phototropic;** i.e., they move away from the light. If heat is applied at some point, an ameba moves in the opposite direction, exhibiting **negative thermotropism. Negative chemotropic** reactions are observed when a reagent like hydrochloric acid or methylene blue is added to the water at some point near the ameba. These responses of the ameba, unlike the tropistic curvatures of plant organs, are not the result of unequal growth but of the inherent mobility of the protoplasm.

Tropisms of one kind or another are manifested by practically every type of living organism, both plant and animal, from the lowest form to the highest. The mechanisms of response and the general behavior, particularly in animals, exhibit an increasing specialization and complexity, reaching a climax in the highly specialized muscular and nervous tissues whose reactions are responsible for self-determined behavior as well as that of a merely tropistic nature.

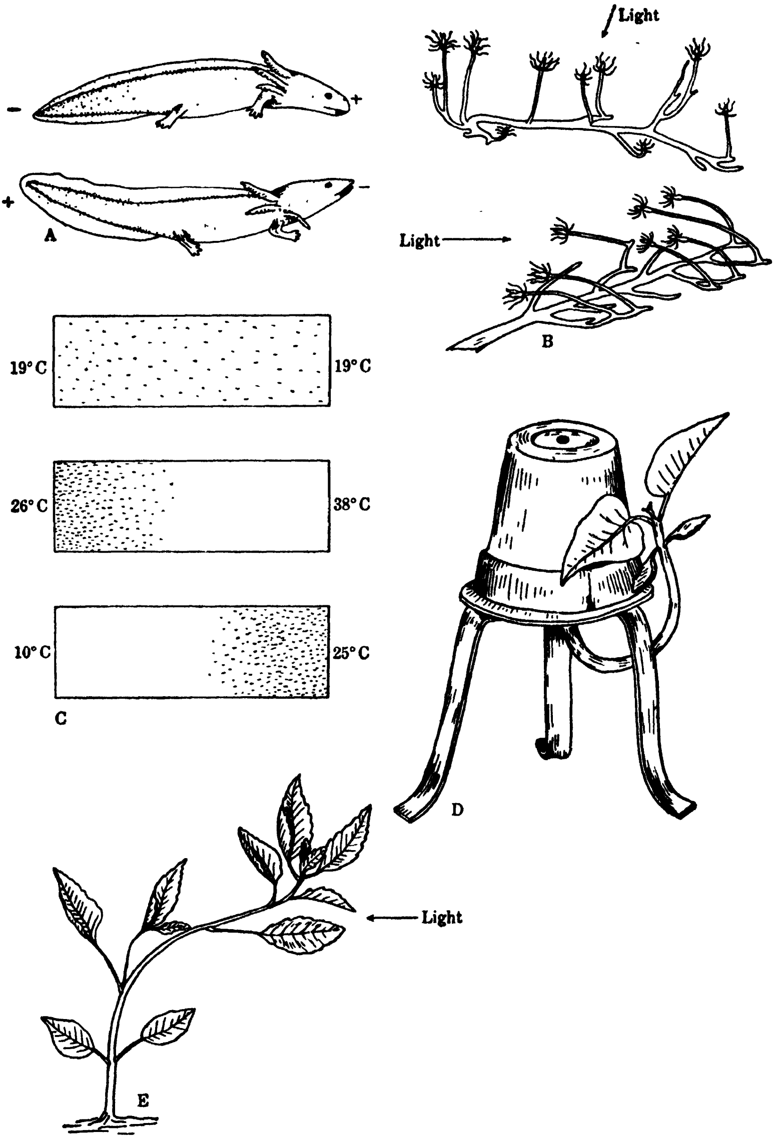


FIG. 108. Tropisms in animals and plants. *A,* electrotropism; reaction of *Ambystoma* larva to electric current. Note the change in position when the current is reversed. *B,* phototropism; reaction of polyps of *Eudendrium* (animal) to changes in source of light. *C,* thermotropism; reaction of paramecium to changes in temperature. Note that the animals react positively to optimum temperature. *D,* geotropism; reaction of an inverted bean seedling to gravity. *E,* phototropism; the plant reacts positively to light. *A and B, from Loeb, "Forced Movements, Tropisms, and Animal Conduct." By permission of the publisher, J. B. Lippincott Co. C, after Mendelssohn and Jennings.*

HOW PLANTS ADJUST THEMSELVES

Tropistic responses are most frequently involved in the adjustment of plants and plant organs. The reactions of the plant to light and gravity have been mentioned previously; such tropisms are responsible for the advantageous adjustment of both shoot and root to their respective environments. Many other illustrations of tropisms involving flowers and fruits could also be given.

Nastic movements. During their early development leaves grow more rapidly on the outer side. Since young leaves usually elongate

FIG. 109. *A*, normal tomato plant. *B* and *C*, tomato plants showing nastic movements induced by ethylene. *Photographs furnished by P. W. Zimmerman, Boyce Thompson Institute for Plant Research.*

faster than the axis or stem, the increased growth on the outer side causes them to curve inward over the end of the stem, forming a bud. When the bud is opening, the inner side of the leaf is growing more rapidly, causing the leaves and bud scales to curve away from its central axis. Curvatures such as these are called **nastic** movements, and, like some tropisms, they are the result of unequal growth on opposite sides of the organs concerned. Unlike tropisms, all of which are induced by stimuli that act more forcibly from one direction, nastic movements are usually responses caused by external stimuli that affect plant parts uniformly on all sides, such as temperature and diffuse light. Leaves and the petals of flowers most

often exhibit nastic movements. These organs are so constructed that their movement can take place only in certain limited directions.

If the growth is greater on the upper side, the leaf bends downward **(epinasty)**; and if the lower surface grows more rapidly the leaf bends upward **(hyponasty)**. Epinasty can be produced in the leaves of tomato plants by exposure to ethylene, a constituent of manufactured illuminating gas. Concentrations as low as 0.1 part of ethylene in 1,000,000 parts of air are sufficient to produce the nastic response. Such minute quantities cannot be detected by odor or chemical tests, but tomato plants placed in a greenhouse will reveal the presence in the atmosphere of mere traces of ethylene by exhibiting epinasty of their leaves (Fig. 109).

Circumnutation. A common and interesting plant movement is that of the elongating tip of a young twining plant. As the stem

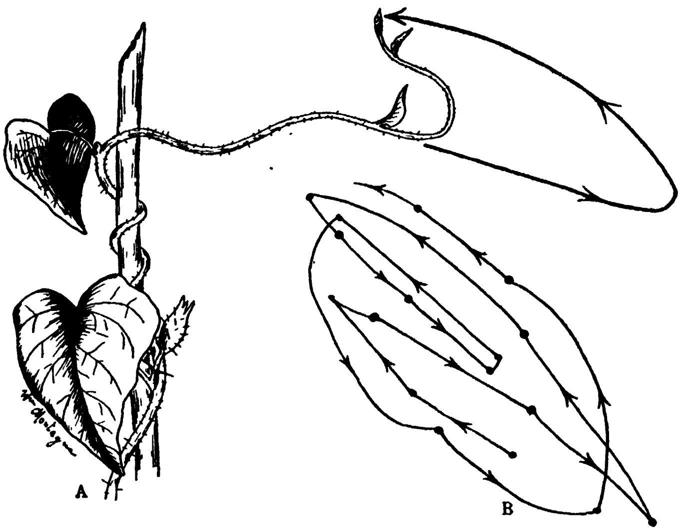


FIG. 110. Circumnutation. *A*, the tip of a twining plant undergoes a growth response causing a revolving movement. *B*, path described by a writing lever attached to a circumnutating stem tip. (*After Darwin.*)

emerges from the soil it grows nearly erect, and the internodes elongate rapidly (Fig. 110). Later, the stem bends over until the top part comes to have an almost horizontal position. The elongating stem tip now swings slowly about in a more or less circuitous path, a movement called **circumnutation** (*circum*—around; *nutare*—to nod). Finally it may come in contact with some support about which it begins to twine, forming each coil at a higher level than the preceding one, thus constructing a neat spiral. The twining of

the stem about its support is apparently caused by differential growth induced by a contact stimulus. Though nutatory movements may be most readily observed in twining plants, emphasis must be placed on the fact that all growing stem tips exhibit nutation.

Some tropisms, nastic movements, and nutations are examples of growth movements caused by unequal growth of the cells. We have already noted that cell elongation is initiated by the influence of auxins, and it is now believed that all growth movements are related to the unequal distribution of auxins in the tissues concerned. In phototropism, light impinging on one side of the stem or petiole causes an unequal distribution of the auxins produced in the apical meristem. Elongation of the cells is inhibited on the lighted side and accelerated on the opposite side. Such unequal growth bends the axis in the direction from which the light rays come, and so we say this is an example of positive phototropism. It now seems highly probable that all growth movements are, in the final analysis, the result of the influence of a hormonal mechanism

Turgor movements. In contrast to the movements caused by differences in the rate of growth in different parts of the organ are the movements effected by reversible changes in the water content of certain cells of the tissues. Since such changes involve fluctuations in turgor pressure, the resultant movements are called **turgor movements.**

Ordinarily, leaves and flower parts display turgor movements, as may be seen in the leaves of plants belonging to the bean family, such as peas, beans, clover, and locust. The so-called sensitive plant (*Mimosa pudica*) is the show plant *par excellence*. The leaves of this plant are twice compound; i.e., each primary leaflet is broken up into secondary leaflets (Fig. 111). When the leaflets are stimulated by touch, heat, or various anesthetics, they quickly turn inward, pressing closely against each other and along the sides of the axis to which they are attached (Fig. 111). The influence inducing this reaction travels rapidly (1 to 3 cm. per second) to the base of the petiole, and then the entire leaf droops. Adjacent leaves may also be involved in this movement, indicating that the influence may even be transmitted up and down the stem for some distance. Within a comparatively short time the leaves again assume their usual position. The chief motor organs concerned in these movements are enlargements at the bases of the petioles and stalks of the leaflets called **pulvini** (*pulvinus*—cushion).

Each **pulvinus** has an extra amount of parenchyma, which accounts for its increased size as compared with the rest of the axis (Fig. 112). The anatomy

of the petiole of this leaf is similar to that of the dicot stem previously described. The vascular bundles surround a column of pith, and they in turn are surrounded by a cylinder of cortical parenchyma. However, in the pulvinus these bundles are almost in the center and are surrounded by a relatively large amount of cortex. These cortical cells are somewhat larger and contain an abundance of water. Among them are numerous intercellular spaces (Fig. 112) into which water may move from the cortical cells.

The more central position of the vascular bundles in the pulvinus naturally makes this region of the petiole more flexible. The parenchyma cells in the

FIG. 111. Response of the sensitive plant (*Mimosa*). *A*, leaves in normal position. *B*, position of leaves 10 seconds after plant has been handled. *Photographs furnished by New York Botanical Garden.*

lower half of the pulvinus have thinner walls and a greater amount of intercellular space than those in the upper half. This is the most important region of the motor mechanism. Owing to changes in permeability induced by a stimulus, the parenchyma cells of the pulvinus lose water, which collects in the intercellular spaces. The water loss causes a corresponding loss of turgor in the parenchyma cells, and consequently the leaf droops. When these cells resorb water from the intercellular spaces, the normal turgor of the cells is recovered and the leaf is raised to its original position. Although this is a satisfactory explanation of the movement of the leaf itself, the causes of the permeability changes that permit the water movement into and out of the cells have been the subject of much discussion. It is now fairly well established that the stimulus inducing the changes in permeability is a hormone transported by the xylem. It is worthy of note that the cell changes involved in these turgor movements are **reversible**, whereas the cell changes concerned with growth curvatures are **irreversible.**

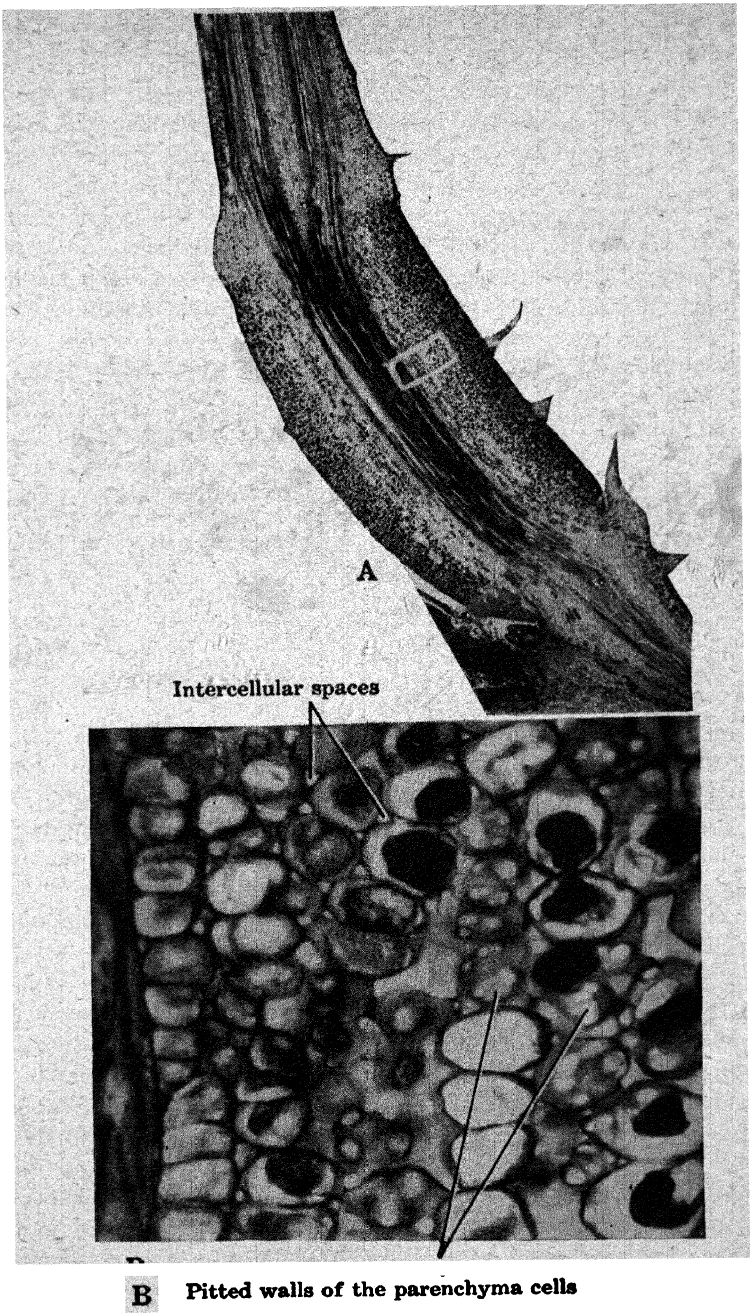


FIG. 112. *A*, structure of the pulvinus of the sensitive plant (*Mimosa*). *B*, a highly magnified portion of *A* taken from the region indicated by the rectangle. *Photomicrograph by H. Lee Dean.*

Photeolic movements. The "closing" of the leaves of clover, oxalis, locust, and other plants, at night, has been inappropriately called "sleep movement," but it should be emphasized that it has nothing at all in common with sleep as it occurs in animals. Such movements are brought about by turgor changes in the motor organs (pulvini) when stimulated by changes of light intensity and resultant changes in temperature. Since these more or less regular leaf movements are induced primarily by light variations, the more appropriate name for them is **photeolic movements** (*photos*—light; *aiolos*—quick moving).

Since there is no sudden change from day to night and from night to day, there is no reason why any evening and morning leaf responses should be anticipated, especially such as are implied in the term "sleep movements." It can be demonstrated that a gradual movement of the leaves occurs throughout the day in response to the gradual variations in light intensity, the highest and the lowest positions being reached during the hours of darkness. The plant becomes so accustomed to these periodic variations that when it is subjected to continuous darkness it will continue to produce these movements during a period of three to five days, the movements gradually becoming less and less noticeable until finally they cease altogether.

HOW ANIMALS ADJUST THEMSELVES

One of the most striking differences between animals and plants lies in their methods of adjustment. In some of the simplest responses, such as the various tropisms, there is a marked similarity when only the reaction of the animal as a whole is considered. But the mechanics which bring about this response by the animal and plant, when analyzed, are seen to differ greatly. This difference becomes more striking in the higher animals.

As already pointed out, every adaptation on the part of an organism involves three general phases: **reception,** that is, the initiation of a physicochemical change by a stimulus; **conduction,** that is, transmission of the **impulse** initiated by a stimulus to various parts of the organism; and **response** or **effect,** which is the reaction the organism makes to adjust to the stimulus. In the higher animals to effect this adjustment there are **receptors,** sensory cells and their processes, which may be scattered or localized as organs of special sense; **conductors,** which are various types of sensory and motor nerve cells with their processes; and **effectors,** which may be either muscles that react in movement or glands that react by secreting.

The simplest animals have all three functions localized in a single cell; that is, every cell is its own receptor, conductor, and effector.

Some parts of the cell may serve as receptors, as the pigment spots of certain simple organisms which may be affected by light. In the epithelium of a simple animal called hydra there are cells whose external, exposed surface acts as a receptor, and on whose inner, basal region are contractile fibrils which are the forerunners of a separate muscular tissue found in the higher animals. In other animals, such as *Vorticella,* contractile fibrils called **myonemes** (*mys*—muscle; *nema*—thread) may be present, which may bring about the contraction of the animal. Conduction of the impulse takes place through the general protoplasm of the cell. However, as animals increase in complexity, cells and groups of cells are found which may be specialized as receptors, conductors, or effectors. Two of these functions (reception and conduction) result in the formation of some type of **nervous tissue** and **nervous system.**

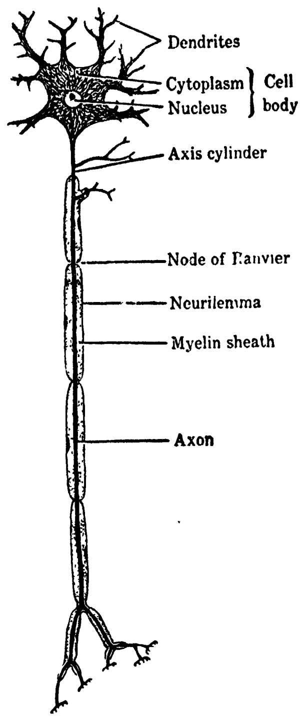


FIG. 113. A typical neuron.

Nervous tissue. The structural unit of nervous tissue is called a **neuron** (*neuron*—nerve). A neuron consists of the **cell body** and its processes, of which there are usually two kinds, **dendrites** and **axons** (Fig. 113). Dendrites (*dendron*—tree) may be either long fibers with much-branched endings or short processes branching close to the cell body. They serve to conduct nerve impulses, induced by stimuli, toward the cell body. Axons (*axon*—axis) are usually fairly long fibers which branch at the free end at quite a distance from the cell body. They may reach a length of several feet and may carry the nerve impulse to the next neuron in a chain of neurons or, if terminal, may discharge the impulse into a muscle or gland. They usually conduct impulses away from the cell body. Thus a neuron may be said to have both structural and functional **polarity** since structure and function differ in the two parts of the cell.

The axons of certain neurons may be invested by sheaths. The inner sheath or **myelin sheath** (*myelos*—marrow) is made up of white, fatty material surrounded by a transparent cellular outer sheath, the **neurilemma** (*neuron; lemma*—skin). These coverings

are supposed to insulate the nerve fibers and increase the speed of conduction. The myelin sheath is interrupted at intervals by the **nodes of Ranvier.** Neurons are held together by supporting tissue. They receive their nourishment and lose their wastes through the blood. The neurilemma is necessary for the regeneration of nerve fibers (Fig. 113).

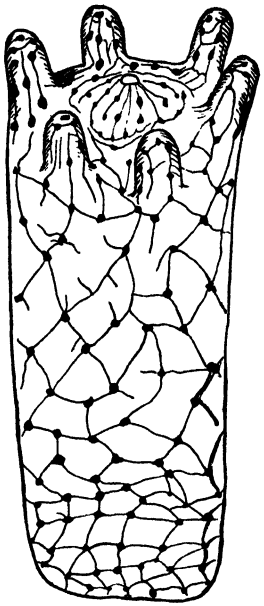


Fig. 114. Nerve net of hydra. *Redrawn from Curtis and Guthrie, "Textbook of General Zoology." (After Hadzi.)*

Nervous systems in general. In some of the simpler animals (hydras, corals, and their relatives), the nerve cells are found mostly under the outer body layer, or outer epithelium, where they form a diffuse, netlike meshwork of nerve tissue which has been designated a **nerve net** (Fig. 114). Investigation has shown that the nerve cells of this meshwork are separate units in contact with each other only. This type of nervous system transmits in all directions equally well, for there are no definite paths of transmission and no centralization.

In certain jellyfishes there is a nerve ring around the circumference. This construction results in a diffuse transmission of impulses and usually a very general response which involves large regions of the organism. Connected zigzag strips cut from the body wall of the sea anemone are affected by the stimulation of only one strip. The basal region of a sea anemone from which most of the animal has been removed will continue to creep about.

In most of the higher animals, beginning with the worms, the nervous tissue becomes more localized, or centralized, to form linear cords called **nerve cords.** In certain regions of these cords nerve-cell bodies are often grouped to form a **ganglion.** From the ganglia the processes of the nerve cells may be grouped into a sort of cable called a **nerve,** usually leading off to various parts of the animal. In insects, when specialized structures such as mouth parts, wings, and legs develop, the ganglia may shift positions and often fuse. In worms, insects, crayfish, and their close relatives, the nerve cord is made up of two longitudinal cords. In vertebrate animals there is one central, tubular nerve cord called the **spinal cord,** which is enlarged at its anterior end to form the **brain.**

Reflexes. The operation of the nervous system depends upon the way the neurons are connected and grouped into systems, which in-

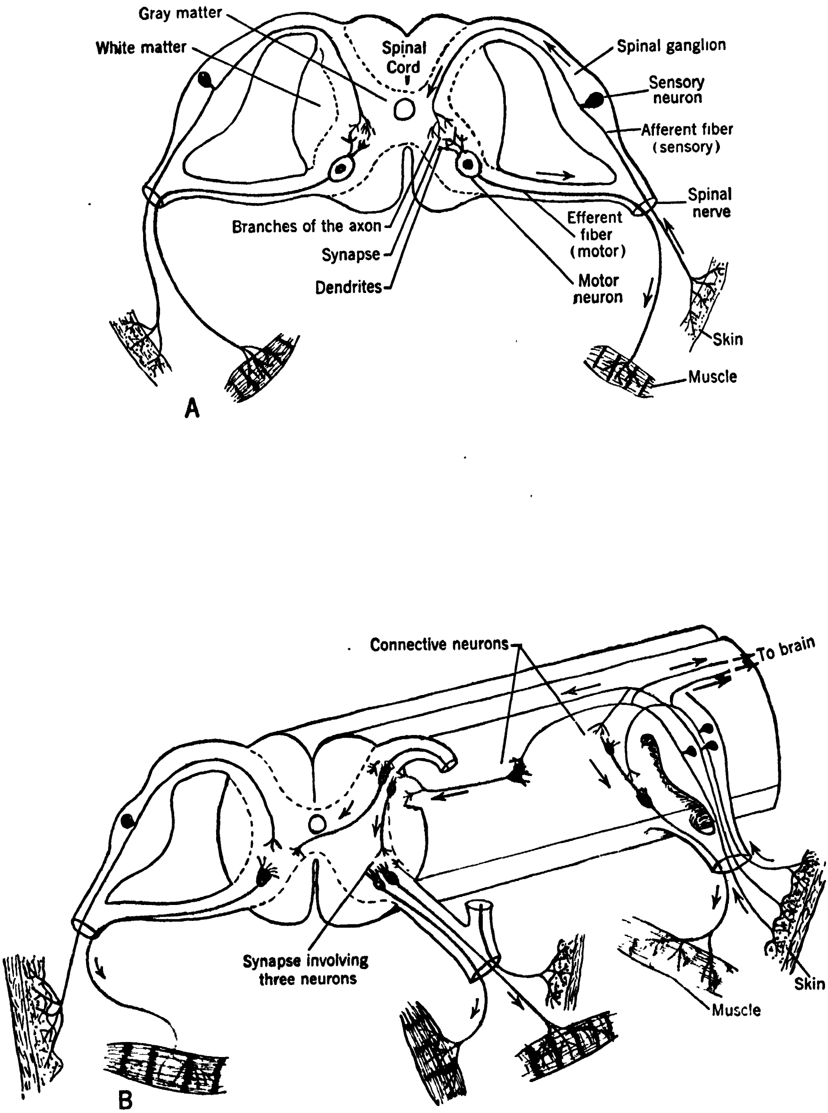


FIG. 115. Reflexes. The functioning of the nervous mechanism. *A*, diagrammatic cross section of the spinal cord with a pair of spinal nerves showing relation of the neurons and the mechanism of a simple reflex arc. Arrows indicate the path of a nervous impulse. *B*, diagram of the adjustor mechanism involved in a more complicated nervous reaction. *Modified from Curtis and Guthrie, "Textbook of General Zoology." By permission of the authors and of the publisher, John Wiley & Sons.*

volves the relative position and endings of the dendrites and the axons. The foundation for the understanding of the nervous system and its functioning is the **reflex arc.** Theoretically, in a vertebrate animal two neurons are necessary in a simple reflex arc involving the spinal cord. However, it is probable that in the higher animals at least three neurons are involved. One of these, called the **sensory neuron,** receives the stimulus from the fine-branched endings of its process among the cells of the skin. The cell body of this sensory neuron is located in a ganglion with other sensory neurons, near the spinal cord. This ganglion is called a **spinal ganglion** (Fig. 115).

For purpose of illustration we shall consider the simplest form of a reflex arc, made up of two neurons. The axon of the sensory cell ends in the spinal cord, where it comes in functional contact with the dendrites of another neuron, the **motor neuron,** which is in the ventral horn of the cord. This region of functional contact is known as a **synapse.** The axon of the **motor neuron** extends from the spinal cord to a muscle or a gland and may be enclosed in the same bundle or nerve with the sensory fibers of the sensory neurons, as well as other motor axons. This nerve is a **spinal nerve** (Fig. 115).

How these cells function. A nerve impulse, or state of excitation caused by a stimulus, is transmitted by the process of the sensory neuron to the cell body. The impulse passes through the cell body, out the axon, and across the synapse to the dendrite of the motor cell. It then passes through the motor cell body, and along the axon to the muscle which is stimulated to contract. If the ending is in a gland, the effect of the stimulus may be the discharge of glandular secretions. Thus we may say that impulses are carried to the spinal cord by **afferent** or **sensory fibers,** and that they leave by the **efferent** or **motor fibers.** An action brought about by an impulse which travels around a reflex arc is called a **reflex action.** Since reflex actions are known to occur in animals without a central nervous system, it follows that a reflex arc need not involve a central nerve cord. It is probable that most reflex actions involve many neurons instead of the simple reflex arc just described.

In man and other higher animals, this receptor-conductor-effector mechanism reaches a degree of complexity, of specialization, of such delicate balance that one can only with difficulty appreciate its workings. To this system man owes much of the coordination of his bodily movements and the extraordinary development of his intellect and emotions which, rather than his other systems, separate him from other animals. An understanding of man as a social and spiritual being as well as a biological organism involves some knowledge

of his nervous system. An understanding of the life and behavior of other organisms, high or low in the scale of complexity, rests upon the study of the adjusting mechanism. We have seen and analyzed the simplest of these responses, and we shall now attempt further analysis by a more detailed study of **receptors, conductors** including the adjustment mechanism, and **effectors.**

RECEPTORS

Receptors are specialized cells, or highly developed cellular structures, which are readily affected by stimuli of various kinds. They are the sensory endings of the afferent nerve fibers. Most of our knowledge of the functioning of these specialized structures has come from the study of the receptors in man and other higher animals. Although we have little exact information about the actual sensations of the lower animals, we have been able to draw some conclusions on the basis of their behavior when subjected to the same general experiments as those made on man. Receptors may be divided into three general classes: the **interoceptors** (*inter*—inward; *capere*—to take); the **exteroceptors** (*exter*—outward; *capere*); and the **proprioceptors** (*proprius*—one's own; *capere*).

The interoceptors. These are receptors located in the respiratory system, the alimentary tract, and other internal organs of the body. Thus the sensation of hunger comes from the stimulation of certain receptors in the stomach walls when the empty stomach contracts producing what are called "hunger pains." Thirst receptors, located in the throat, are apparently stimulated by osmotic changes due to water loss. Other interoceptors are involved in pain, fatigue, nausea, and sexual sensations.

The exteroceptors. These are the receptors through which we become aware of our changing relations with the outside world. According to the stimuli which activate them, they may be grouped as chemical receptors (in man, in the nose and tongue); light receptors (in man, in the eye); temperature (in man, in the skin); mechanical (in man, the ear; pressure in the skin). The eye, ear, and nose have sometimes been called **distance receptors** because they are stimulated from sources not in contact with the organism.

CHEMICAL RECEPTORS—TASTE AND SMELL. In man and other vertebrate animals, taste receptors known as **taste buds** are found mostly on the upper surface and sides of the tongue. The taste buds are imbedded for the most part in the numerous small projections called **papillae** (*papilla*—small pustule) which cover the tongue and give it a

velvety appearance. The taste bud opens upon the surface through a pore (Fig. 116). The dissolved substances entering the pore stimulate the nerve endings in the taste buds, and the impulse set up by the stimulus is conveyed to the brain. These chemical receptors can be stimulated by substances in solution only, and they seem to be receptive only to stimuli which give the sensations of sweet, sour, bitter, and salty. One cannot taste with a dry tongue. Other flavors which we seem to "taste" are really experienced through our smell receptors, or through the joint action of smell receptors and taste buds As we all know, a severe "head cold" robs us of our taste so that we have a tendency to use more sugar and salt in our food. When we have such a cold, vanilla ice cream seems to us to be just so much frozen sweetened cream. There is no vanilla "taste" because the mucous membrane of the nose is so inflamed and covered with mucus that the sensory endings cannot be stimulated. Oils are unpleasant because of their "feel" rather than their taste.

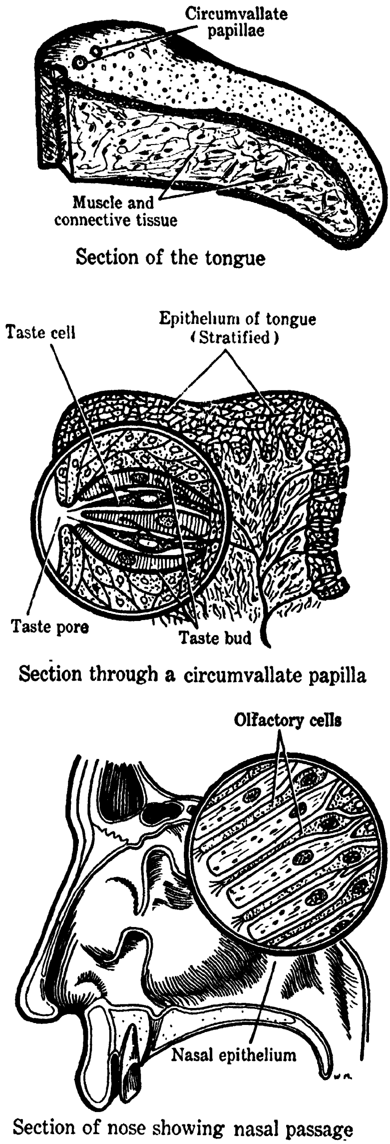


Fig. 116. Chemical receptors of taste and smell.

Just as the taste receptors are stimulated by substances in solution, so the olfactory receptors are stimulated by substances which are finely divided or in the form of gases or vapor. It has been said that smell is "taste at a distance." In man these receptors are located in a portion of the **olfactory epithelium** which lines the nose. The material which may be smelled does not stimulate the olfactory receptors directly but must be dissolved in the fluid covering the

mucous membrane containing the receptors. The olfactory receptors are in functional synaptic contact with the endings of the olfactory nerve, which leads to the brain (Fig. 116). Smell is used by animals not only for discovering food but also for avoiding enemies and finding mates in the breeding season.

In insects, the olfactory receptors are in the **antennas** or "feelers," located on the head. It is also possible that these receptors may be found in other parts of the body. Flies and carrion beetles which feed on, and lay their eggs in, carrion, will find concealed decaying flesh even though it is enclosed in a box and hidden from sight. Aided by their olfactory receptors, ants find their way to the nest and recognize their nest mates. Jordan describes an instance where some female moths (*Promethea*) were enclosed in a box and kept in a building. No males of this particular kind of moth had been seen in the vicinity at the time, yet a few hours after the females were placed in the box, more than forty males were found about the building.

MECHANICAL RECEPTORS—THE EAR. In backboned animals, the mechano-receptors for hearing and equilibrium are developed for the most part in a common organ, the ear. The mechanical principles and structures of organs of equilibrium are essentially similar. The general plan of structure calls for a **vesicle** lined with sensory, hair-like **receptors,** whose cavity is filled with a liquid in which may be one or many freely movable solid particles (Fig. 117). When an animal changes its position, the liquid with these concretions or particles—sometimes they are grains of sand—shifts about and comes in contact with different groups of the lining sensory hairs. These they stimulate. The new impulse is carried to the brain (in higher animals), and proper adjustments are made. In some animals, such as clams, oysters, and crayfish, these organs are called **statocysts** (*statos*—standing; *kystis*—bladder).

In the shrimps, animals which resemble and are related to crayfish, the statocyst opens to the outside. When the animals molt, that is, lose their hard outer shell, they lose the sand grains from their statocysts as well. Kreidl placed some shrimps, just after they had molted, in a dish with iron filings instead of sand grains, and the shrimp placed iron filings instead of sand grains in the statocyst. He then brought into play an electromagnet which shifted the particles, but not the animals' position, and observed that the animals turned over on their backs, thus accommodating themselves to the stimulus.

In vertebrates, from fishes to man, the equilibrium part of the ear consists of two small saclike chambers called the **utriculus** (*utriculus*—little skin bag) and the **sacculus** (Fig. 117). In addition to these

structures there are three **semicircular canals** both ends of which connect with the utriculus. The utriculus and the sacculus contain specialized end organs made up of a group of cells with hairlike processes called **hair cells.** Fastened to the hair cells are concretions of calcium carbonate called ear stones or **otoliths.** The hair cells are well supplied with nerve endings; hence any movement of the head

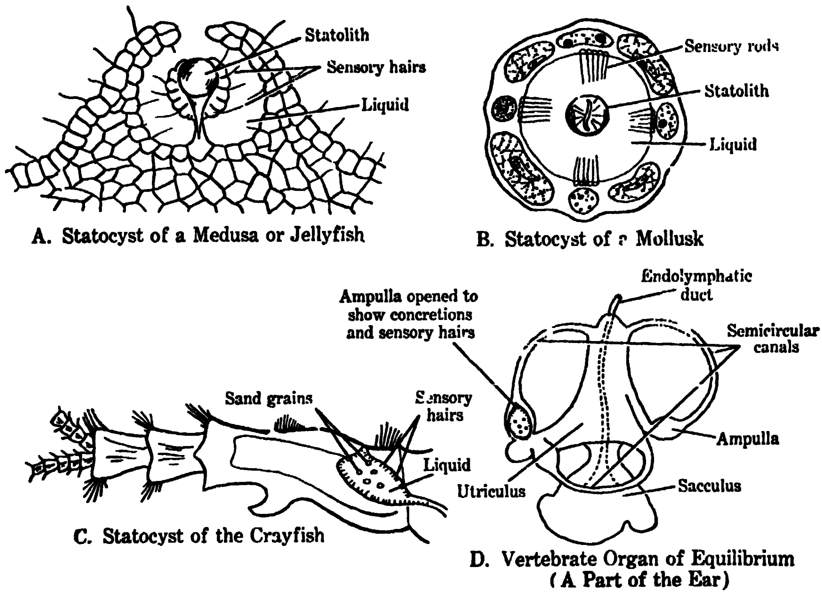


FIG. 117. Organs used in maintaining equilibrium. In all these organs there is the same general structural plan: a cavity lined with sensory hairs and containing a liquid in which there usually are some floating particles. *A and B, redrawn from Dahlgren and Kepner, "Principles of Animal Histology." By permission of the publisher, the Macmillan Co., modified from Huxley, "The Crayfish."*

changes the position of the otoliths and sets up a reflex which may result in a righting reaction on the part of the organism. In man, apparently, the utriculus and sacculus are concerned with the relation of the body, as directed by the head, to the changes of gravity. In other words, when the eyes cannot assist in orientation, as when a person dives into deep water or an aviator flies blindly, the ear structures tell us which way is up or down. In addition to these mechanisms, the eyes also function in head and body-position adjustments.

The semicircular canals are arranged in three planes approximately at right angles to one another (Figs. 117 and 118). The canals contain a fluid. Motion of the head in any plane sets the

liquid in motion, which stimulates certain sensory hairlike structures and assists man to a large extent in the maintenance of his equilibrium. This equilibrium mechanism and those equilibrium mechanisms of the invertebrates are really to be considered parts of the proprioceptor system.

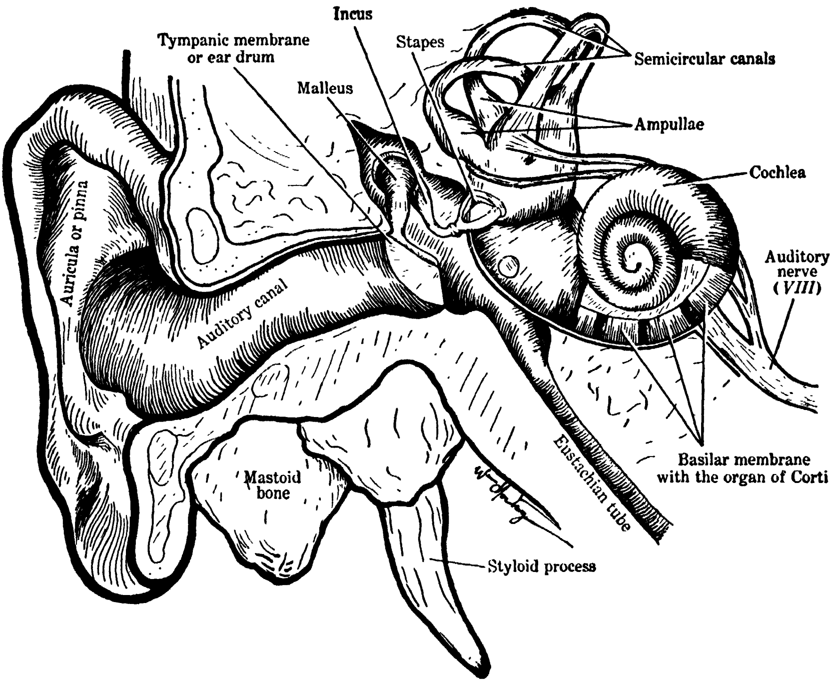


Fig. 118. Diagram of the anatomy of the human ear.

An ocean voyage often causes too much change of position and overworks the vertical canals of the equilibrium mechanism, inducing seasickness. In testing the fitness of prospective aviators for the Army Air Service, one of the most important tests is a test of the semicircular canals, to see whether they are functioning normally. The candidate is placed in a special chair and whirled rapidly in various planes and directions. His adjustment time is then observed and measured.

Hearing is the perception of certain vibrations of bodies which give rise to sound waves. The sound waves spread out from the vibrating body in all directions and may be transmitted to animals through air or water. The organs of hearing of various animals are mechanical devices which receive the vibrations. The vibrations create a state of excitation which, in the form of a nerve impulse, is carried by a nerve (the **auditory**) to the brain, where it is interpreted.

The organs for sound perception vary in complexity in different animals, reaching their highest degree of complexity and perfection in man and other mammals. In man there is an external appendage, the lobe or **pinna,** in common parlance "the ear," which is useful in collecting sound waves and determining direction of sound. Leading from the pinna into the head is a small tubular passage, the **auditory meatus** (*meatus*—passage), which ends in a chamber, the **tympanic cavity** or **middle ear** (Fig. 118). The opening of the auditory meatus into the tympanic cavity or middle ear is closed by a fold of tissue, the **tympanum** or **eardrum.** By this arrangement the tympanum is subjected to pressure through the auditory meatus. Any sudden increase in pressure, like an explosion, might burst the drum. Such an incident is taken care of by the **Eustachian tube,** a passage which leads up from the pharynx to the middle ear, and thus the tympanum may have approximately equal pressure on both sides. This construction also allows more freedom for the vibration of the eardrum.

Sudden changes in atmospheric pressure, such as are encountered in changes of elevation, often cause an uncomfortable sensation of "deafness." This sensation is sometimes experienced when one goes up rapidly in an elevator or rides over a mountain in an automobile. The condition can be relieved by yawning or swallowing, which opens the Eustachian tube and permits air to enter the middle ear, thus equalizing the pressure on the two sides of the eardrum.

The essential organ of hearing is the **cochlea** (*cochlea*—snail), a spiral, fluid-filled sac enclosed in bone. This region of the ear is separated by constriction from the utriculus and the sacculus, the portions of the ear concerned with equilibrium. The semicircular canals, utriculus, sacculus, cochlea, and associated structures make up the **inner ear** (Figs. 118 and 119). The tympanum is connected to the fluid-filled cochlea of the inner ear by a chain of three bones **(malleus, incus,** and **stapes),** which is found in the middle ear (Fig. 118).

This mechanism works as follows. Sound waves come in through the outer ear and set the tympanum in vibration.

The following statement from Howell serves to clear up what is meant by sympathetic vibration. "If one stands in front of a piano with the strings exposed and sings a given note it may be shown that a series of the piano strings is set into vibration corresponding to the rate of vibration of the fundamental tone and secondly to the more prominent harmonic overtones."

The vibrations of the tympanum, by causing vibrations of the chain of these bones, are transmitted to the liquid of the cochlea. The diameter of the cochlea decreases as successive coils become smaller, and a **basilar membrane,** made up of tautly stretched trans-

verse fibers attached at each end to the walls of the cochlea, is suspended in the liquid of the cochlea (Fig. 119). The basilar membrane is equipped with the **organ of Corti,** made up of hair cells which are overhung by a membrane (Fig. 119). These sensory hair cells connect with the brain through the **auditory nerves.** High notes or tones may affect regions where the fibers are shortest, correspond-

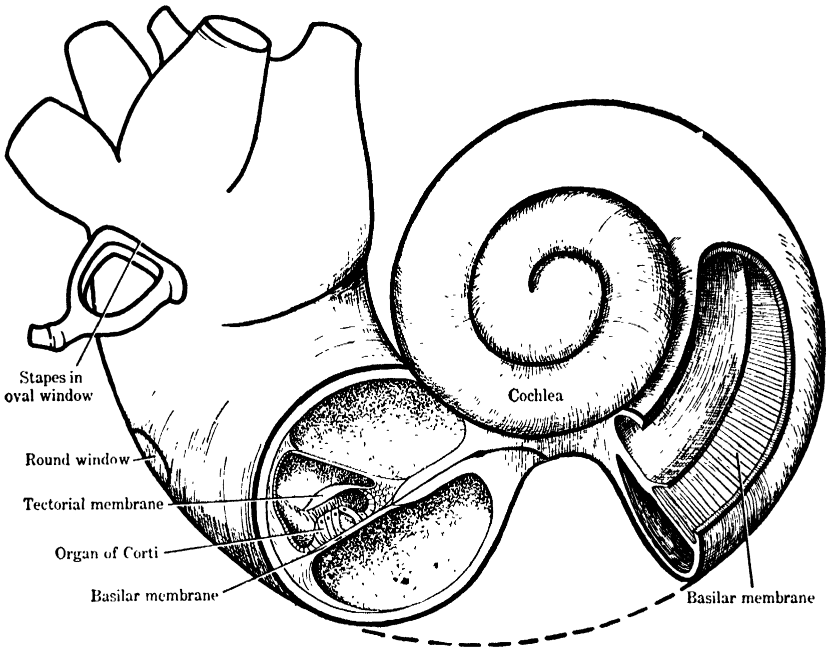


FIG. 119. Diagram showing the auditory apparatus of the inner ear. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

ing to the short strings of the piano; low notes or tones affect the longer fibers corresponding to the long strings of the piano or bass. The vibrating fibers of the membrane, in turn, move the hair cells, which strike the overhanging membrane, bringing about stimulation in the hair cells and setting up an impulse which is carried to the brain.

Apparently when the ear is stimulated by sound vibrations the organ of Corti within the cochlea causes changes in electrical potentials which have the same frequency as the sound waves. Wever and Bray exposed the auditory nerve of a cat and connected it with a telephone in another room by means of electrodes and a vacuum-tube amplifier. Words and musical notes sounded at the cat's ear could be heard distinctly through the telephone.

Deafness may result from several causes. The eardrum may have burst or become hardened so that it is unable to vibrate, hence, sound waves or vibrations fail to reach the inner ear unless they are very intense. To be heard one must shout. Other causes of deafness may be the closure of the outer passage by "wax," defects in the bony chain, defects in the cochlear region, or a degenerating auditory nerve.

The lower vertebrate animals have no outer ear, no chain of bones, and no spiral organ of Corti. In the frog, the tympanum is at the surface of the body and connected to the inner ear by a single bone. In some animals, including man to some extent, sound vibrations are carried to the auditory nerve through the bones of the head. In fishes, sound waves are transmitted by vibrations in the water. Vibratory movements in the water are probably imperceptible to us, but the fishes have a system of cutaneous and subcutaneous sense organs, called the **lateral line organs,** which respond to these slow vibrations. The lateral line extends along each side of the body as a longitudinal groove.

It is very difficult to prove that insects hear. Forel believes that they do not hear as we do but that their receptors for sound are more like our tactile organs. However, invertebrates may have some sense of hearing, because they produce sounds, some so high-pitched that the human ear cannot perceive them. Moreover, some insects have been observed to respond to the call of their mates and to artificial imitation calls. The grasshopper has a pair of external tympana which connect with a vesicle and a nerve. Hearing organs are located on the antennas of some insects and on the legs of others.

Light Receptors. When the word sight is mentioned, we at once think of the human eye, an organ which can function only with the aid of light. However, light perception or reception, and consequent stimulation, does not necessarily mean image projection, as can be seen from a study of the so-called "eyes" of simple animals. These are very properly called **photoreceptors.** In many of the one-celled animals and plants, the photoreceptor consists of an "eye spot" or pigment spot which is sensitive only to changes in light intensity. In fact, all protoplasm is more or less sensitive to light. Often there is material in the surface epithelium of an animal which registers changes in light intensity. The earthworm has specialized sensory cells for light perception and responds quite readily to a beam of light flashed upon it. The anterior or head end is more sensitive than the posterior. Similar evidence seems to indicate that photoreceptor cells are present in oysters, clams, and other animals.

THE EYE. **A true eye is concerned with form and color perception as well as with change in light intensity.** It is an organ which consists of a photosensitive surface like the plate or film of a camera and a mechanism, a **lens,** that focuses the light on this sensory surface. Further, a true eye has nervous connection with the brain which interprets these photographed images.

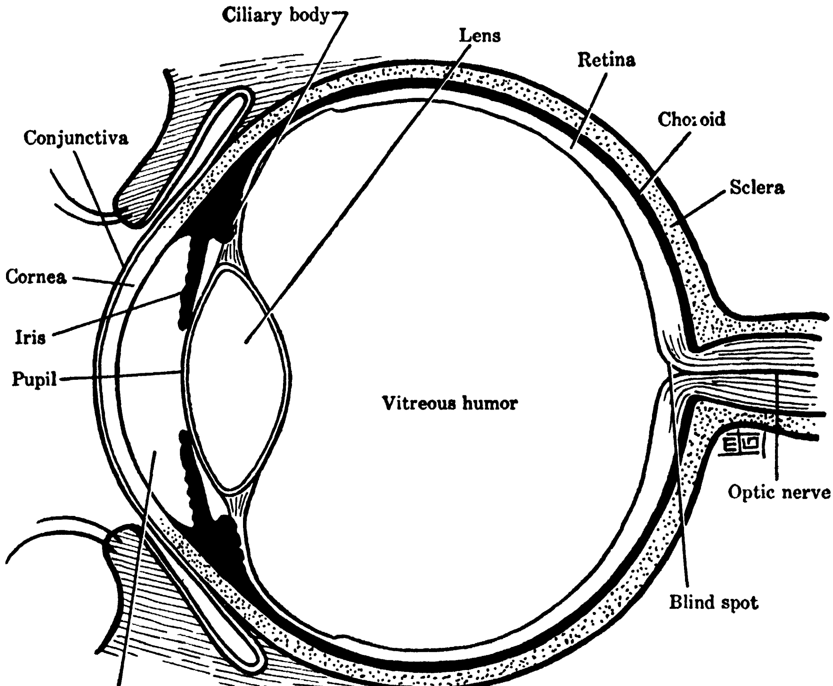


FIG. 120. Diagram of a section of the human eye. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

In its structure and working the eye has often been compared to a photographic camera. The outer tough **sclera** or "white" of the eye is the box of the camera. The **cornea** is a transparent region of the sclera, which may be compared to the opening in the box through which light enters (Fig. 120). Under the sclera will be found the **choroid coat,** darkly pigmented and containing many blood vessels, which may be likened to the dark lining of the camera. Some of the pigmented choroid seen through the cornea forms the **iris** or colored part of the eye. The round opening in the iris is the **pupil** of

the eye, just back of which is the **lens.** The inner lining of the eye is the **retina** (*rete*—net), which contains photoreceptor cells; it is comparable to the sensitive film or plate of the camera. The eye is kept rigid and turgid by the **aqueous humor** (*aqua*—water; *humor*—moisture) and the **vitreous humor** (*vitreus*—glassy; *humor*). The watery aqueous humor fills the chamber between the cornea and the lens, and the more viscous vitreous humor fills the space between the lens and the retina.

How the Eye Photographs. The eye is "pointed" toward the object to be photographed by muscles which rotate the eyeball in the socket; or the animal may turn its head. The light rays are brought to a focus on the retina principally by the cornea and the lens. In some animals the lens may change its position; in others, its shape. The change in shape of the lens is brought about mainly by the **ciliary muscles** in the iris. Thus, the closer an object is held to the eyes, the thicker the lens becomes. This is called **accommodation.** To bring out the image more clearly, just as in the camera or microscope, the amount of light must be regulated. This is done by the iris, which acts like a diaphragm to change the size of the pupil. The object is now clearly focused on the retina, upside down as in a camera. In the retina there are millions of specialized receptors called **rods** and **cones.** The rods are stimulated only by light and dark; the cones are sensitive to color. If we saw only by the rods, our world about us would appear in black, white, and gray. We owe the perception of color to the cones. Rods are used mostly for night vision, the cones becoming quite blind. Under normal conditions these receptors are stimulated and nerve impulses are carried to the brain by the **optic nerve.** The brain then constructs the image in its true proportions and colors.

The surface of the eye is kept moist by tears from the **lacrimal gland,** located in the upper and outer region of the orbit of the eye. The tears flow down across the eyeball and drain into the tear duct, which opens into the nose. Tears serve to lubricate the eyeball and the eyelids and also to keep the delicate outer covering of the front of the eye, the **conjunctiva,** from becoming dry and inflamed.

Blindness may be the result of derangements of various parts of the eye. In this respect, Clendening continues the camera comparison as follows: "The plate may be fogged or broken; the retina may be diseased. The lens of the camera be dirty; the lens of the eye may be blurred by cataract." Blindness may be due to atrophy of the optic nerve, as a result of the hardening of the arteries, Bright's disease, or diabetes. Cataract may be the result of an infection or malnutrition. This condition can be remedied by removing the lens,

"A simple operation in competent hands."[1] The lens of the eye glass takes the functional place of the one removed.

Among other causes of defective vision is the lack of adjustments in the lens of the eye, which results in improper focusing. If the image is to be brought out clearly and not to appear blurred, it must be focused sharply on the retina. Some people are said to be farsighted, which means that, with the lens in a "normal" state, the image comes to a focus behind the retina **(hyperopia).**

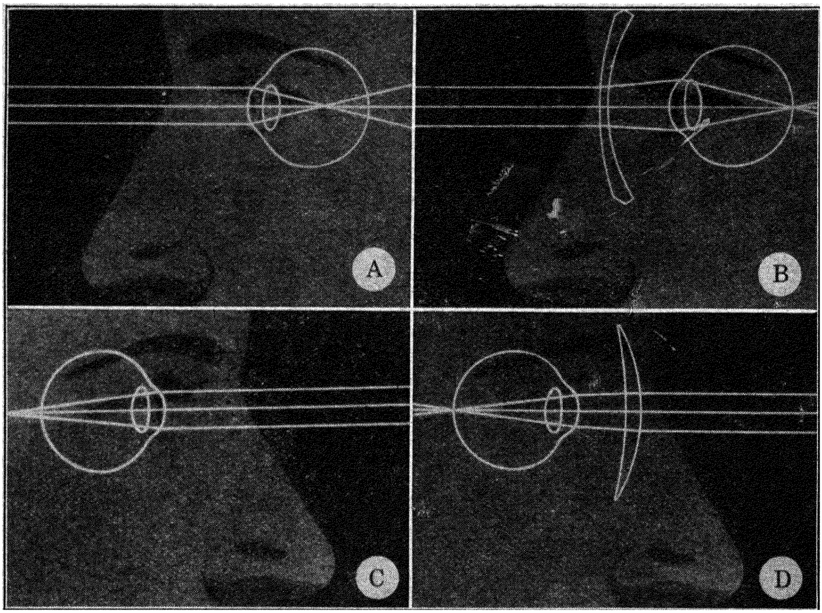
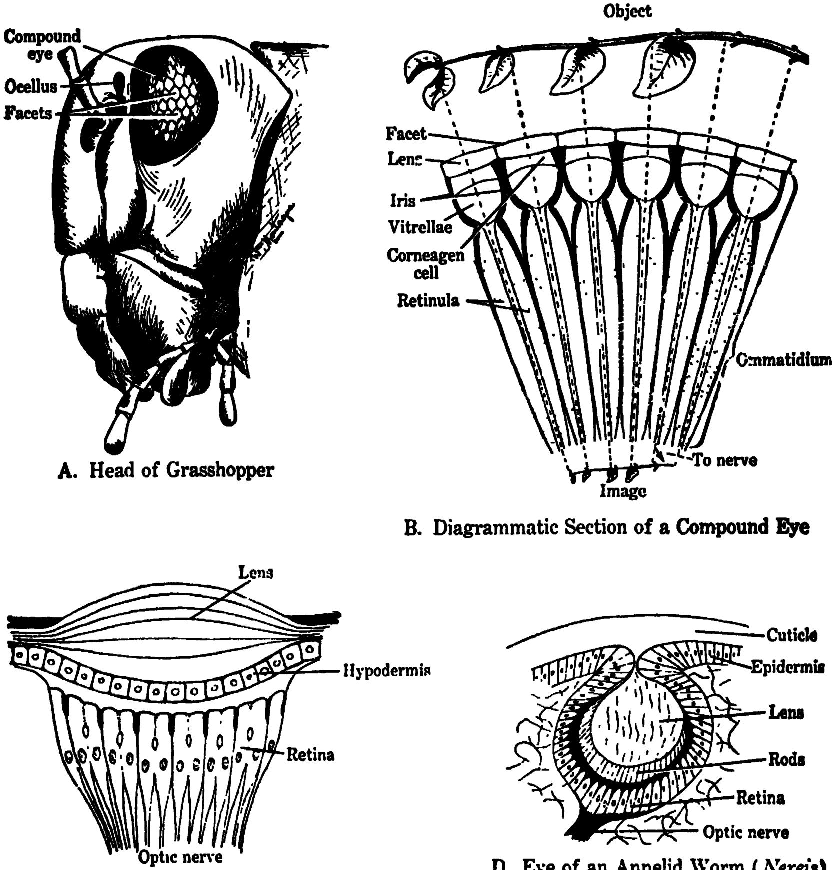


Fig. 121. *A,* condition found in myopia (image formed in front of the retina). *B,* condition corrected by a lens. *C,* condition existing in hyperopia (image formed back of the retina). *D,* condition corrected by a lens. *Courtesy of the Bausch & Lomb Optical Co.*

In other persons, said to be nearsighted, the image is focused in front of the retina **(myopia)** (Fig. 121). Farsightedness can be corrected by wearing glasses with convex lenses, and nearsightedness, by glasses with concave lenses (Fig. 121).

Eyes of Invertebrates. Some eyes of invertebrate animals resemble superficially the general plan of structure just described, but most invertebrate eyes are used mainly for light perception and, in many invertebrates, for the detection of motion. There is usually a tough covering corresponding to the **sclera,** and the eye proper has a **lens** and a sensory retinalike structure (Fig. 122). Eyes of this type are found in certain mollusks, annelids, and spiders, and in the **simple eyes** or **ocelli** of insects. The focal length of such eyes is

very short. The invertebrate eye which most closely resembles the "camera eye" of man is that of the squid, in which the arrangement of the layers of retinal cells is just the reverse of that in the vertebrate eye.



A. Head of Grasshopper

B. Diagrammatic Section of a Compound Eye

C. Ocellus

D. Eye of an Annelid Worm (*Nereis*)

FIG. 122. Compound eye of insects, mosaic vision, and eyes of other invertebrates. *C, redrawn from Comstock, "A Manual for the Study of Insects." By permission of the Comstock Publishing Co. D, redrawn from Hegner, "Invertebrate Zoology," after Andrews. By permission of the publisher, the Macmillan Co.*

Crabs and insects have what is known as a **compound eye,** consisting of a number of small simple eyes called **ommatidia** (*omma*—eye); the simple eyes in a single compound eye may vary from 7 to 27,000 in number.

Each **ommatidium** or **eye** has a lenslike organ and a group of **photosensory cells** or **retinula** which corresponds to a **retina** (Fig. 122). Each ommatidium is isolated from adjacent ones by cells containing black pigment. The **retinulas** of the compound eye are connected to the brain by nerve fibers.

The compound eye is supposed to produce **mosaic vision.** Each ommatidium receives a single impression from a different region of the object looked at. The sum total of all the impressions sent to the brain gives a complete picture of the object observed. Hegner suggests that this method of image formation "may be well adapted for recording motion, since any change in position of large objects affects the entire 2,500 ommatidia" (Fig. 122). Compound eyes can see objects at a distance of 7 to 10 feet. It is probable that the image "photographed" by the compound eye is more blurred than that taken by the eye of man.

Apparently, insect eyes differ from those of man in more respects than structure. Lutz has shown in an interesting series of experiments that ultraviolet light rays which are invisible to human eyes are visible to insects, but, on the other hand, insects are color blind to red, which appears gray to them. Lubbock confined some ants in a box, into one region of which ultraviolet light entered through a prism. Another region was illuminated by red light. To human eyes the ultraviolet end would appear dark, and the red end, light. The ants hurried into the region illuminated by the red rays. Flowers of different plants which seem to man to be alike in color may have a different color pattern to an insect if one flower reflects ultraviolet light and the other does not. To the insect, even the color patterns of other insects are different from those seen by man. At least they appear different in photographs made of objects which reflect only the ultraviolet. Lutz concludes that there is a possibility that this reaction is "not vision in the usual sense of the word" but may be "a complicated physiological phenomenon."

TOUCH. The mechanical receptors responsible for touch are found on the free surfaces of almost all organisms. As pointed out, the touch receptors are located in the protoplasm of all external cells. In some lower animals, certain structures such as the antennas of insects and crayfish have specialized tactile organs in the form of stiff, tactile hairs or bristles. In the higher forms we find various types of tactile mechanisms. The cat's "whiskers" are supposedly tactile in function. In man, sensitivity in touch is not uniformly distributed but is restricted to certain areas which can be mapped out. In these areas are found specialized end organs called **tactile corpuscles** (Fig. 123). The sensation of pressure is very similar to that of touch but is perceived by the stimulation of different receptors **(Pacinian corpuscles).**

TEMPERATURE AND PAIN RECEPTORS. In addition to the receptors for touch and pressure there are located in the skin other receptors for warmth, cold, and pain. These receptors are grouped in special spots. Pain spots contain no special receptor—just free nerve endings. The warmth and cold receptors are scattered over the body in different areas. Thus in the skin of the face there are few cold spots but many warm spots; on the other hand, there are few warm spots

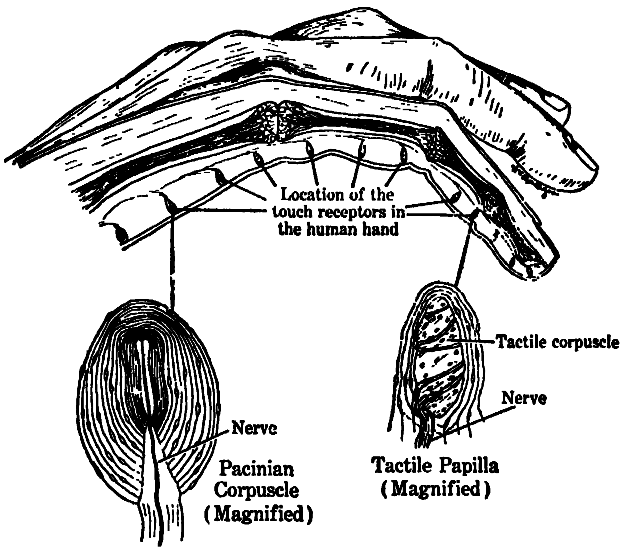


FIG. 123. Touch and pressure receptors.

in the mucous lining of the mouth and pharynx, an arrangement which enables us to drink extremely hot tea and coffee. So far as it is known these thermal receptors occur only in warm-blooded animals.

Proprioceptors. The proprioceptors furnish information about muscular tension and movement which result in body position and locomotion. They are located in the muscles, tendons, and joints, and in certain parts of the ear (utriculus, sacculus, and semicircular canals).

THE ADJUSTMENT MECHANISM

We have seen that various agents, such as chemicals, light, and heat, may act as stimuli to arouse and excite various specialized receptors in an organism. Further, certain tissues, especially nerv-

ous tissue, are adapted not only for excitation or reception of stimuli but also for transmission. We have just studied various specialized adaptations of the nervous system for the reception of stimuli, such as the eye, taste buds, ear, and tactile corpuscles. From these special sensory regions a state of excitation, set up by stimuli, is transmitted along the nerve fibers as a **nerve impulse.** In the sensory structures, the nerve impulse travels toward the **central nervous system,** which is made up of the **brain** and **spinal cord.** In the central nervous system, various necessary adjustments and coordinations are usually made as a result of the stimuli, and a fitting response in the form of a nerve impulse is sent out to the effectors, which are muscles and glands. The neurons of the central nervous system are the units that make up the adjustor mechanism.

The nervous mechanism. The nervous mechanism in man and other vertebrates is made up of three systems: the **central,** the **peripheral,** and the **autonomic nervous systems.** The central nervous system consists of the spinal cord and brain. The peripheral nervous system consists of the nerves which leave the spinal cord, called **spinal nerves,** and the nerves which leave the brain, called **cranial nerves.** The autonomic nervous system (*auto*—self; *nomos*—province or self-governing) is an auxiliary system of ganglia and nerves regulating and controlling most of the internal organs, such as those of the alimentary tract, the heart, and the arteries, which are not under the control of the will.

The central and peripheral nervous systems. The **spinal cord** in vertebrates is enclosed in a canal in the backbone of the animal. The paired spinal nerves leave it at regular intervals along its length. Each nerve has two roots in the cord, a **dorsal root** and a **ventral root** (Figs. 115 and 124). The dorsal root is made up of **afferent, sensory fibers** which arise from the cell bodies of **sensory neurons in** the spinal ganglion close to the nerve cord where the sensory root emerges. The ventral root is made up of **efferent fibers** from cell bodies of neurons found in the nerve cord. The fibers from these two roots enter the same sheath. It is estimated that there are approximately 630,000 nerve fibers in the dorsal root, and 200,000 fibers in the ventral root, of a spinal nerve.

There are two main regions of the spinal cord: an outer one called the **white matter,** made up of nerve fibers some of which are surrounded by myelin sheaths; and an inner one, made up mostly of nerve cell bodies and dendrites, called the **gray matter.** The nerve cells in the gray matter of the spinal cord are either **motor neurons** or **connective neurons.** The myelinated fibers of the white matter

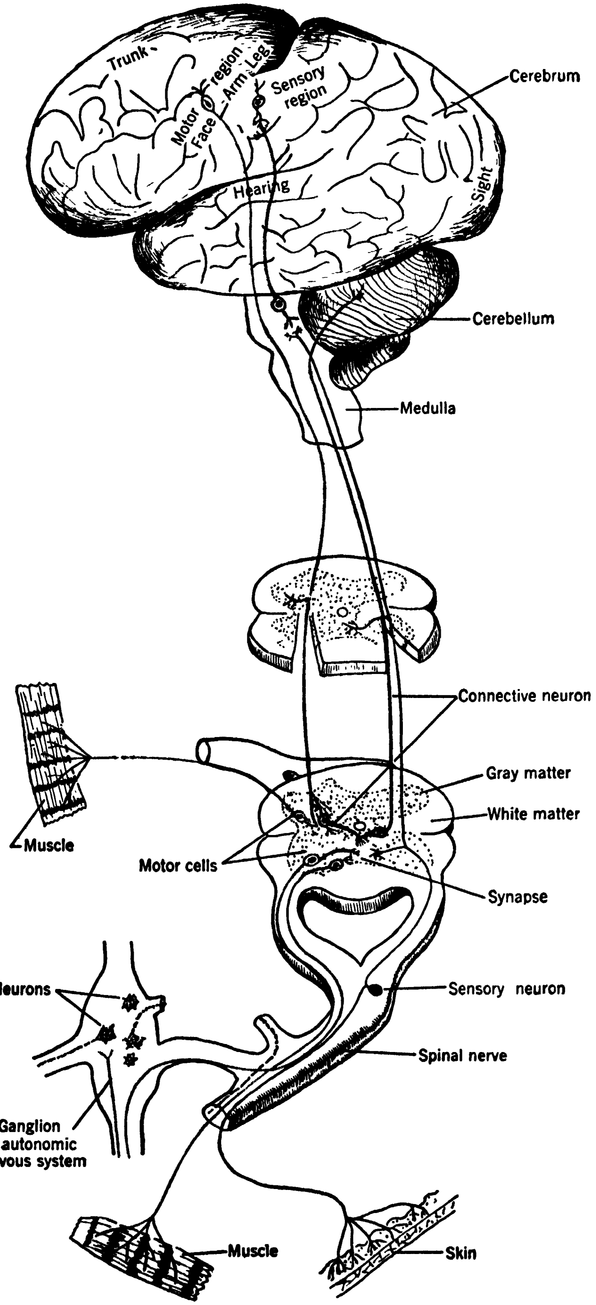


FIG. 124. Diagram showing the functioning of the brain and spinal cord.

are: afferent fibers of sensory nerves, which may run lengthwise through the cord and end in the brain; axons of connective neurons of the gray matter of the cord or the brain; and efferent fibers running to the spinal nerves. These regions and relations are brought out in Figs. 115 and 124, which should be carefully studied.

The brain is the highly differentiated region at the anterior end of the spinal cord. In vertebrate animals, five general regions are recognized, only three of which will be considered here: the **cerebrum,** which is most anterior; the more posterior **cerebellum;** and the most posterior **medulla oblongata,** which merges into the spinal cord (Fig. 124 and 125).

The five general regions recognized in the vertebrate brain are: the **telencephalon** (*tele*—far; *enkephalon*—brain); **diencephalon** (*di*—second); **mesencephalon** (*mesos*—middle); **metencephalon** (*meta*—after); **myelencephalon** (*myelos*—marrow). Figure 125 shows the general relationship of these brain regions in various vertebrates.

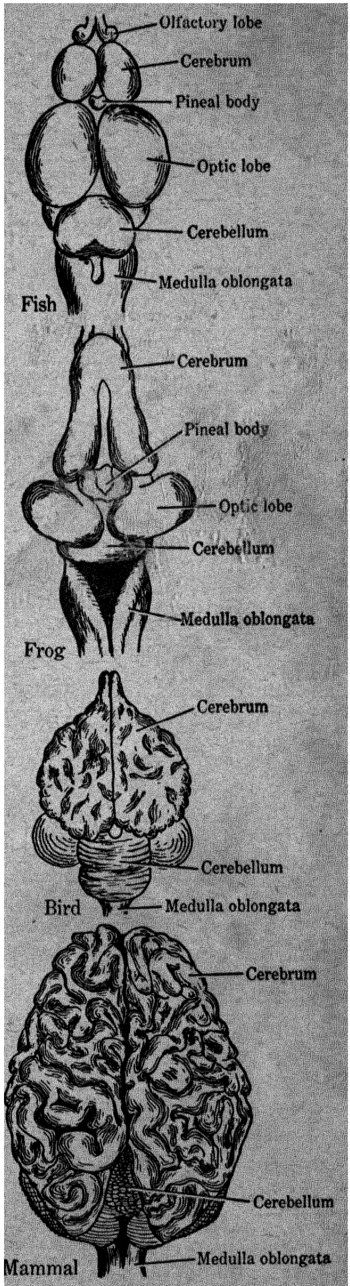


FIG. 125. Comparable regions of the brains of various vertebrate animals.

THE CEREBRUM (TELENCEPHALON). A study of Figs. 124 and 125 shows that the cerebrum is made up of two hemispheres which become much enlarged and more pronounced from fishes to man. In man, where it covers and dwarfs the other regions, it is much folded. There is an outer region of **gray matter** called the **cerebral cortex** which follows these folds and covers the underlying **white matter.** There is an essential similarity between man and the lower animals in the function of the various brain regions except the cerebrum. A frog

whose cerebrum has been removed behaves quite like the normal unoperated animal. There is little loss in vital function in birds and dogs after removal of the cerebrum except that the dog loses what he has learned. The animal will eat only when food is placed in the mouth. The development and differentiation of the cerebral cortex make man what he is. Failure of this structure to develop means idiocy. The cerebrum is the region of thinking, memory, voluntary motion, consciousness, and mental life generally. These activities are carried on by the estimated 10,000,000,000 neurons of the cortex. Experimental studies have shown that certain areas of the brain may control certain activities. These regions were mapped as shown in Fig. 124. The areas not so marked are called the **association areas,** and it is here that such processes as learning, recall, imagination, and reasoning take place. However, Lashley has demonstrated that, in rats, the functional areas are not absolutely fixed, but that if one region of the cerebrum is destroyed another will take over its functions. He found that some rats, when he destroyed as much as 80 per cent of the cerebrum, could continue to learn. However, certain regions such as the auditory and visual seemed to be specific.

The brain pattern of man seems to be more fixed than that of a rat. In 1848, a quarryman named Gage was tamping a blast which exploded suddenly and drove a crowbar through the left side of his jaw and out through the top of his head in the frontal region. He lived for 12 years after this and could hear, see, taste, smell, and perform voluntary movements. However, his temperament and disposition were affected. He would go into fits of rage and wander away. He would not work, and he became dishonest. After he died in convulsions, an autopsy showed that the left prefrontal portion of his brain was destroyed. Probably some of the adjacent regions had been injured also. Theoretically, this region is responsible for the qualities that were impaired.

The functions of other areas have been discovered by the ingenious method of opening the skull and stimulating certain areas of the brain with an electric needle. For example, one small area stimulated will cause an animal's thumb to twitch, and if a wider area is stimulated the entire arm comes into action. Other areas stimulated give specific reactions of other body regions. Not only have these functional areas been determined by destruction and stimulation, but post-mortem examinations of the brains of handicapped individuals, including the mentally sick (insane), have shown tumors and various other defects in certain regions. Some indication of the brain pattern is thus ascertained from the behavior of these unfortunates. Recently, by electrical devices, it has

been possible to trace the path of nerve impulses from the various sense organs to certain brain regions.

THE CEREBELLUM (METENCEPHALON). This region of the brain is the center for reflex coordination, equilibrium, motor coordination, and muscular tone—in other words, an organ of motor control. Destruction of this region of the brain results in jerky, ineffective, uncoordinated muscular movements. It is almost impossible for the hand to pick up anything, and the affected person "reels drunkenly" when he tries to walk. No function of "consciousness" seems to exist in the cerebellum. In man, stimulation of the cerebellum is not felt. Its cortical region or gray matter is estimated to contain 1,000,000,000 neurons. Into it come the relay fibers from the skin, the joints, the eyes, the ears, the muscles, and from the cerebrum itself. The following illustration adapted from Clendening brings out the function of the cerebellum more clearly. A golfer is urged to keep his eye on the ball when he is trying to hit it. His eyes are 6 feet from the ball and his hand 3. Why should his looking at the ball help him to place one tiny space on the face of his club within $1/64$ of an inch of the spot on the ball which will send it farthest and straightest? Because of his cerebellum, which receives fibers from the center of vision in the cerebrum, from the semicircular canals, and from his muscles and joints. All these together give him a sense of space, distance, and muscular steadiness. The cerebellum makes connections with the motor centers sending fibers to his muscles; the result is a motor sense of "placement." Thus the functions of sight, equilibrium, feeling, and motion are brought together and integrated. A good athlete needs a good cerebellum.

It will be noted, from a study of Fig. 125, that size and complexity of the cerebellum vary with the motor activity and structure of the animal. In frogs and salamanders, rather sluggish animals having poorly developed powers of locomotion, the cerebellum is very small; in the much more active birds, it is relatively very large and well developed.

THE MEDULLA OBLONGATA (MYELENCEPHALON). This posterior region of the brain gradually merges into the spinal cord (Figs. 124 and 125). The medulla receives stimuli from the viscera through the autonomic system. It is the center which regulates such automatic or unconscious, yet vitally important, functions as the heart beat, blood pressure, and movements of the lungs in breathing. It controls body temperature, the involuntary movements of the intestinal tract, and the action of various glands. A frog with all the brain cut away except the medulla continues to breathe normally

and to swallow pieces of food placed in its mouth. The animal may even continue to live for a long time with all the brain missing except the medulla.

THE AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system regulates the internal organs of the animal, such as the alimentary tract, lungs, heart, blood vessels, bladder, and glands. In general, we might say that it regulates those structures having involuntary muscles. In man it is beyond the direct control of the will and takes care of the "routine drudgery of life." In other words, one cannot deliberately cause the heart to beat faster or change the rate of intestinal peristalsis. There seems to be good reason for believing that this system is influenced by emotional reactions. Stimuli that result in emotional reactions also affect the autonomic nervous system and glands of internal secretion. We have already seen that emotional stimuli, such as fear and anger, often add to adrenal activity, which results in increase in blood pressure. Stage fright is usually accompanied by dryness of the mouth and throat. Emotional stress may interfere with digestion because the flow of gastric juices tends to be diminished as a result of the cutting off of the normal blood supply to the alimentary tract. It is well known that many digestive disturbances can be traced directly to worry or excitement.

This system is sometimes known as the involuntary nervous system. Anatomically it consists of two divisions, the **parasympathetic division** centered in the sacral region of the cord and parts of the brain (medulla and midbrain) and the **sympathetic division** made up of two chains of connected ganglia extending along each side of the spinal cord in the thoracic and lumbar regions (Fig. 126). Sensory neurons of the autonomic system are found in the spinal ganglia, and motor neurons are located in the spinal cord. Fibers from these neurons are found in the dorsal and ventral roots of the spinal nerves. In addition, fibers originating from ganglia of the autonomic system may be present in the roots of the spinal nerves (Fig. 126). Thus it is seen that, by this arrangement, the autonomic system is connected with the central nervous system. Nerve fibers of the autonomic system extending from neurons in the central nervous system to the autonomic ganglia are called **preganglionic fibers,** and those fibers whose neurons are in the autonomic ganglia are known as **postganglionic fibers.** Numerous autonomic fibers as well as ganglia often unite to form a **plexus.** The one most commonly

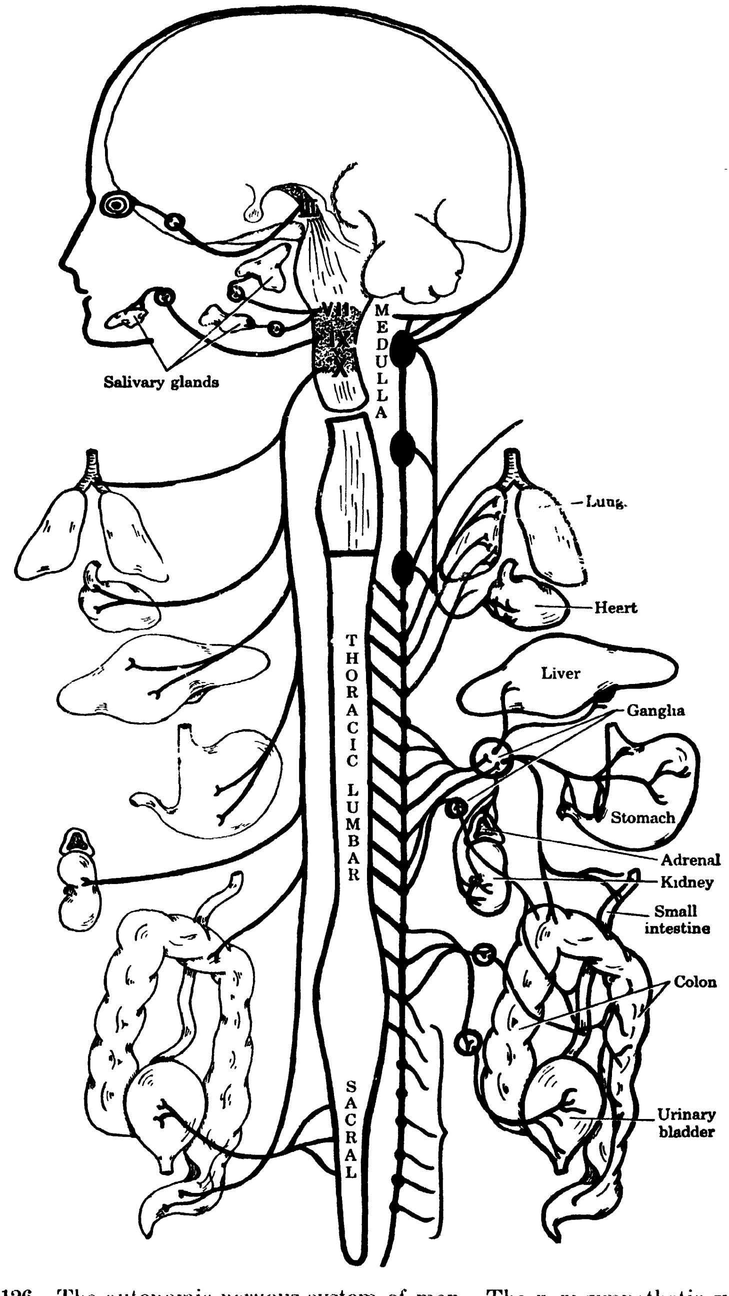


FIG. 126. The autonomic nervous system of man. The parasympathetic system is shown on the right and the sympathetic system on the left. Distribution of nerves is indicated by duplication of the organs.

known in man is the **solar plexus,** which lies in the abdominal cavity. Branches extend from this plexus to the various abdominal organs.

Most of the organs supplied by the autonomic system receive a double set of nerve fibers. One set stimulates or accelerates and the other inhibits or retards a reaction. Many structures, such as the intestines, heart, iris of the eye, and the salivary glands, receive fibers from both the sympathetic and the parasympathetic systems. Usually the actions of the two systems are antagonistic. For example, the heart rate is slowed down by impulses transmitted by the vagus nerve (parasympathetic system, cranial region) and accelerated by impulses from the sympathetic division. The iris of the eye contracts under impulses delivered by the parasympathetic division and dilates when it receives impulses from the sympathetic.

Research has demonstrated that nerve impulses of the parasympathetic system bring about the liberation by the nerve endings of a substance called **acetylcholine,** which, when secreted by branches of the vagus nerve in the heart, causes a slowing of the rate of heart beat. On the other hand the endings of the nerves of the sympathetic system release a substance, sometimes called **sympathin,** which has an effect somewhat similar to adrenalin; i.e., it accelerates muscular contraction. The effects of acetylcholine and sympathin are examples of the action of neurohumors.

EFFECTORS

In our bodies, and also in the bodies of other backboned animals, there are bones—round bones, long bones, flat bones, and others, which collectively make up the **skeleton** (*skeletos*—dried) (Fig. 127). This is such a commonplace fact that it is doubtful that we have ever given much thought to the real purpose of bones. We know they are there and that under normal conditions they function.

The skeleton serves various functions. It is responsible in a large measure for the shape of the animal; without it, many animals would be shapeless, jellylike affairs. Even the lowly sponges have supporting structures of some sort, as we shall see later. Skeletal structures serve for protection. The average observer knows how effectively a turtle is protected within its shell, a type of structure known as an **exoskeleton** (*exo*—outside). Other familiar examples of exoskeletons are the shells of clams, oysters, and other shellfish, and the tough, horny, outer coverings of insects, crabs, and their relatives. An exoskeleton is present in starfish and in various other animals to be discussed later. Vertebrates have an inner skeleton

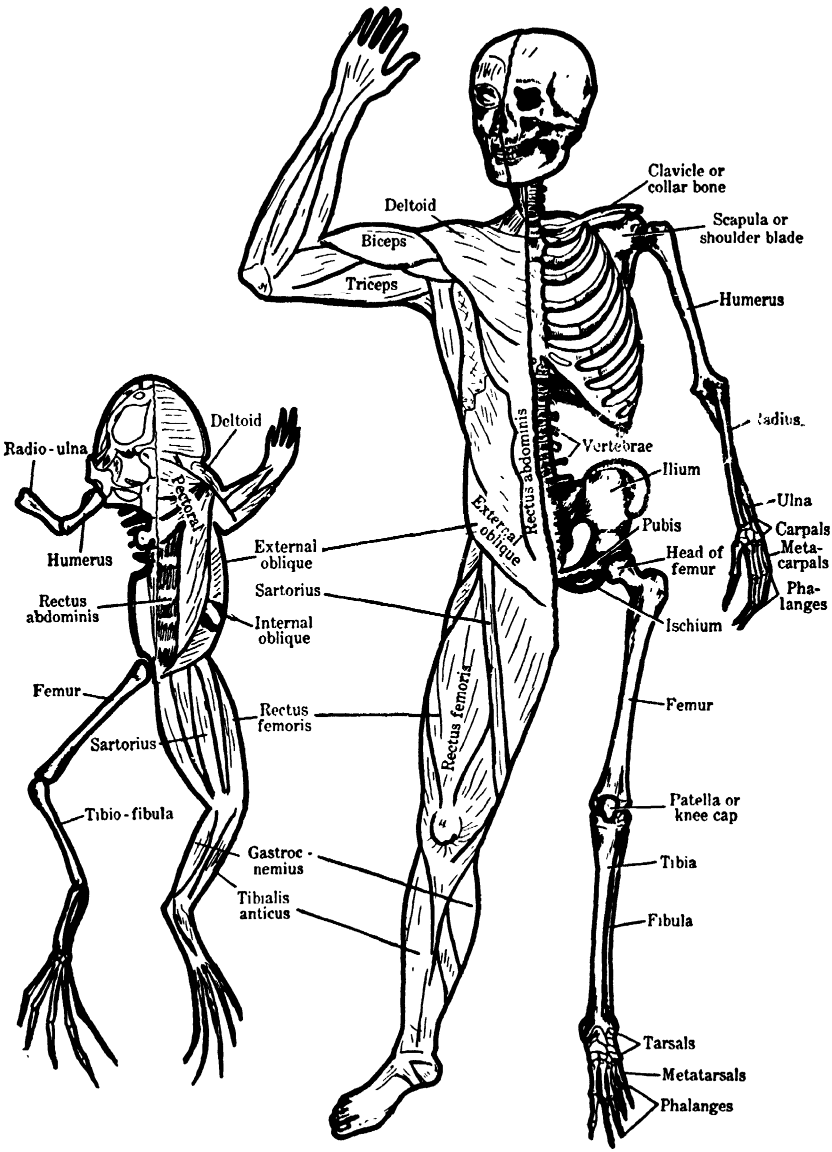


FIG. 127. The bony framework (skeleton) of frog and man together with the muscles that effect movement.

called an **endoskeleton** (*endon*—within). Although not so effective from the standpoint of protection, this endoskeleton permits more agility, a more varied response, and better possibilities for animal adjustment. The skeleton, whether exoskeleton or endoskeleton, is an integral and important cog in the **effecting mechanism,** the tool and machine of the directing nervous system.

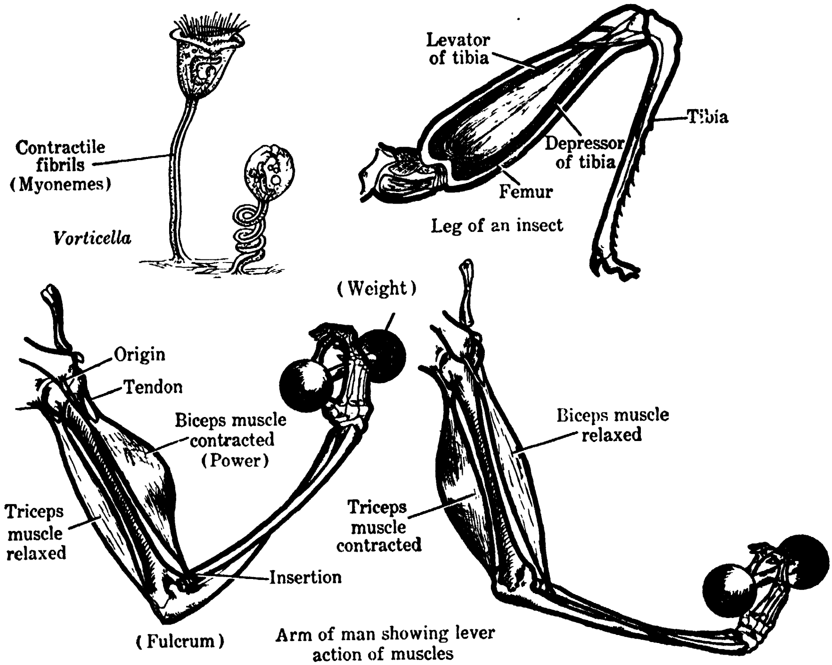


FIG. 128. Effector mechanisms. Note the antagonistic action of the muscles arranged in pairs.

Skeletons of insects, crabs, and vertebrates make up a system of levers, workable by various types of joints (Fig. 128). Attached to these levers at strategic points are muscles which move them, and this mechanism is responsible for the movement of the animal organism in whole or in part. In vertebrates three main types of joints are present: **hinge joints,** found in the elbow and knee; **ball-and-socket joints,** in the shoulder and hip; and **gliding joints,** in the ankle and wrist. At the joints the bones have enlarged ends which afford more surface for articulation. These ends are covered by a smooth layer of cartilage. The whole mechanism is held in place largely by lashings of connective tissue called **ligaments** (*ligare*—to bind). The joint is lubricated by a fluid secreted by the **synovial**

membrane which encloses the joint. The joints of insects, crabs, and their relatives are of the hinged type. In the movement of the exoskeletal coverings of the abdomen, the edge of one segment slides over the edge of the adjacent one—a sort of modified gliding joint.

MUSCLES AND MOVEMENT—EFFECTORS IN ACTION

Arrangement. Muscles work by contracting. When a muscle shortens it changes its shape and not its volume. The shortening or contraction results in a pull and consequent movement of the part to which it is attached, as in the arms and legs, or the region of which it is a part, as in the intestine. After the contraction comes a **relaxation,** or the restoration of the muscle to its original length. No work is done during the period of relaxation. Muscles always work by *pull.* They never *push.* Consequently, in arrangement, muscles are usually found in opposing pairs or groups. Certain muscles, the **flexors,** bend the joint, and others, the **extensors,** straighten it. Often more than one muscle is concerned in the movement of bones in joints such as the hip and shoulder. Frequently the muscles of opposing groups differ in size and strength. Thus the alligator has relatively weak muscles for opening the jaws but more powerful ones for closing them. A man has relatively little trouble in keeping an alligator's jaws closed but is in real difficulty when trying to keep them open. The same general muscle arrangement is true of the large claw (chela) of a lobster.

Muscles at work. Under normal conditions, the skeletal muscles depend entirely upon the nerve impulse to stimulate their activities. If the nerve to a muscle is cut, the muscle relaxes completely and will not respond. The nerve impulse is sent through the efferent nerve fibers to each muscle fiber, which receives it through the **myoneural junction** (*mys*—muscle; *neuron*) (Fig. 129). The muscle fiber responds by a single, short contraction and then relaxes. Analyzed, this reaction of the muscle fiber consists of a **latent period,** that is, the time elapsing between the reception of the stimulus and beginning of contraction; the **contraction period;** and the **relaxation period,** which merges into the **recovery period.** A very simplified explanation of the working of the muscle fibers and, of course, of the muscle is somewhat as follows: apparently, the nerve impulse initiates a chemical reaction in the muscle, as a result of which energy is released and revealed in the form of external work such as lifting weights and movement.

Contrary to popular belief, muscles will contract in the absence of free oxygen. This energy is furnished by the explosive breakdown, without the use of free oxygen, of an organic phosphate compound into an inorganic phosphate. The glycogen in the muscle then breaks down, forming lactic acid and releasing

FIG. 129. Photomicrograph of myoneural junction. *Copyright by the General Biological Supply House, Chicago.*

energy. This energy is used to change the inorganic phosphate back to the organic phosphate necessary for additional contractions. This breakdown of both the organic phosphate compound and the glycogen are anaerobic reactions similar in a way to fermentation, where sugar breaks down into alcohol and carbon dioxide and releases energy as heat. According to some authors the energy released in the anaerobic phase is transformed into muscular contraction; then in the second phase oxygen supplied by the blood is consumed—aerobic respira-

tion—which releases additional energy in the form of heat. Thus we see that oxygen brought by the blood stream is not used directly in muscular contraction. True, rapid and deep breathing brings additional supplies of oxygen to the muscles, but the amount is never sufficient to supply all oxygen needs of the contracting muscles.

Then how does the oxygen function? As the muscles continue their contraction, more and more phosphate change takes place, and more and more glycogen is broken down into lactic acid. Now the oxygen's role is to convert the lactic acid back into glycogen. In so doing it consumes or oxidizes one-fifth of the lactic acid, and carbon dioxide and water are released as waste products.

We see that the athlete doing the hundred-yard dash uses more energy than he had free oxygen to produce, but the glycogen loaned it to him. Thus he built up an **oxgen debt** which is repaid after the race by the continued faster and deeper breathing for a period.

Only 20–30 per cent of the available energy of glycogen of the muscle is manifested in movement. The rest is lost in heat, which is used to maintain a body temperature at which necessary physiological processes can proceed.

The chemical changes involved in muscular action may be represented as follows:

CONTRACTION

Organic phosphates → Phosphate + Organic compounds + Energy (used in contraction)

RECOVERY

Phosphate + Organic compounds + Energy from glycogen breakdown → Organic phosphates

Glycogen → Lactic acid + Energy (resynthesis of organic phosphates)

$$\text{Lactic acid}\begin{cases}\frac{4}{5} \rightarrow \text{Glycogen}\\ \frac{1}{5} + O_2 \rightarrow CO_2 + H_2O + \text{Energy (used to resynthesize glycogen)}\end{cases}$$

Each skeletal muscle is composed of bundles of muscle fibers. When stimulated, each individual fiber making up the muscle receives a separate impulse which does not spread beyond the fiber receiving it. The result is separate reaction for each fiber. The voluntary muscles can be made to undergo various degrees of contraction by stimulating only certain groups of fibers at a time. Thus the arm can be raised partially or completely, depending upon the number of fibers stimulated. This mechanism makes possible the various adaptations of the organism to each situation which confronts it.

The preceding discussion has concerned skeletal muscle, whose structure was previously described under tissues as **voluntary or striated muscle.** Two other types of muscle, **smooth muscle** and **cardiac** or **heart muscle,** were described. These two types of muscle are involuntary. In smooth muscle there is a transmission of the contraction from muscle cell to muscle cell resulting in a wave of contraction which spreads along the structure. This is seen in the

contraction waves in the esophagus when food is swallowed. In cardiac muscles there are no distinct cell boundaries but the tissue is made up of continuous protoplasm. Thus a wave of contraction in this tissue is transmitted very rapidly, and, as a consequence, the entire heart contracts almost simultaneously in an **all-or-none** reaction. The contraction of heart muscle is automatic. The heart of a turtle can be removed and suspended in a vessel containing a solution somewhat like the body lymph and it will continue beating for days despite the fact that the rest of the turtle has long since died. Even small isolated pieces of the heart will show contraction outside the body. Smooth muscle may be directly stimulated by stretching, to which it responds by contracting.

Other effectors. **Cilia** and **flagella** are types of effectors found on some of the simplest animals as well as on various structures of higher animals. The gills of clams are covered with cilia whose beating brings fresh water with oxygen and food to the organism and carries various wastes away. The trachea of man and other higher animals is lined with cilia whose movement expels the dust-laden mucus. In some of the lower organisms, instead of cilia, there are present one or more whiplike structures called **flagella** (*flagellum*—whip) which are essentially similar to cilia in structure and in the mechanism of movement.

We have already discussed various types of glands which are also effectors and have pointed out their function and reactions. There is now set up an adjusting mechanism for the organism. This mechanism is a receptor-adjustor-effector system on whose perfect functioning the life of the individual and of the race depends.

THE NERVOUS SYSTEM IN ACTION

We shall examine more closely but in a general way the manner in which the central nervous system functions in bringing about adjustments of animals. This involves a study of the transmission of, and the paths taken by, the nerve impulses or states of excitation. We recall that the neuron normally exhibits polarity in that the impulse enters through the dendrites, passes through the cell body, and out the axon. The terminal branches of the axon may be in functional contact with the dendrites of another neuron or of many neurons. Such a place of functional contact or junction between dendrites and axons, for usually many neurons are involved, is known as a **synapse** (Figs. 115 and 124). The nerve impulse passes from one neuron to another *only across the synapse*. A somewhat

similar junctional relationship exists where the axon comes in contact with the muscle. This is known as the **myoneural junction** (Fig. 129).

The synapse. The nature and peculiarity of the synaptic junctions influence, in a marked way, much of the behavior of the higher animals. In the first place, a nerve impulse will pass across a synapse only in a certain direction. The synapse has polarity. Thus it is seen that there is "one-way traffic only" through the nerve cells and across the synapse. Experimental evidence indicates that nerve impulses may be slowed up or even blocked at the synapse. The extent of this block may vary under different physiological conditions and in different parts of the same animal. Thus synapses may be affected by certain glandular secretions as well as by toxins formed by the process of metabolism. Loss of oxygen may cause a synapse to lose all capacity for conduction. This is the reason a person may become unconscious when strangled or "half drowned." Certain drugs, among them nicotine and alcohol, may lower the conductivity of the synapse, thus slowing up the time of response and dulling the feeling. On the other hand some drugs increase the conductivity of the synapse so that the slightest stimulus will cause an exaggerated response. An animal in this condition in common parlance is often said to be "nervous."

We have previously pointed out that reflex arcs almost always involve more than just one sensory and one motor neuron. Thus very complicated reflex arcs result from the combinations of many sensory, connective, and motor neurons. Some of the possible combinations are suggested below:

1. The axon of one sensory neuron may be in contact with two or more motor neurons.

2. The axons of two or more sensory neurons may be in contact with one motor neuron.

3. The axons of two or more sensory neurons may transmit the impulse to two or more motor neurons.

4. Connecting neurons may be present, connecting two or more sensory cells or two or more motor cells in the same or different levels in the spinal cord.

Some fishes have a pair of enormous nerve cells on whose dendrites the axons of no less than twelve sensory cells end. In all probability every neuron in the animal body, with the possible exception of the autonomic system, is connected in some way by the synapses with every other neuron. Thus it may be assumed that a nervous impulse starting at one point could spread all over the body, provided

that the same conditions held in all the nerve cells and synapses of the organism.

According to one view this does not happen, for usually the transmission of neural impulses is more or less channeled. Thus the stimulation of one group of receptors results in a response from only a certain group or groups of effectors. The problem before us, then,

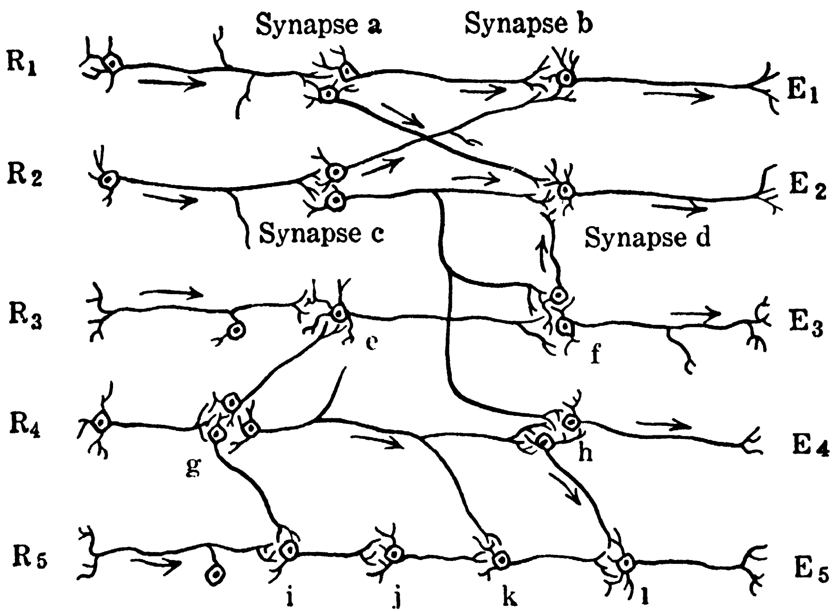


FIG. 130. Diagram showing the possible paths which might be followed by a nerve impulse. *Redrawn from Dashiell, "Fundamentals of General Psychology," by permission of the author and publishers, Houghton Mifflin Co.*

is the determination of the path followed by the nerve impulse. Dashiell * suggests certain physical possibilities as an explanation of this problem. In this connection we must study Fig. 130, in which diagram the neurons are pictured as removed from the spinal cord and arranged end to end in one plane. "For illustration, assume that a stream of impulses is excited at the receptive point R_2. What direction through the nervous system will it take: (1) over the synaptic junctions c and d to E_1, (2) over synapses c and d to E_2, (3) over c and f to E_3 or (4) over c and h to E_4? What are the relations between each neuron and the succeeding one that are the determining factors?"

* John F. Dashiell, *Fundamentals of General Psychology,* Houghton Mifflin Company, Boston, pp. 266–267.

Several theories are offered to explain the pattern of the pathway. One theory is that the synaptic resistances differ greatly in degree and the impulse will follow the path of least resistance. In other words, the behavior of an animal in a given situation will depend upon the differences of resistance at the synapses. This theory, however, has been much criticized. Another theory offered is that the impulse will follow nerve fibers which have the same rhythm of "refractory (inactive) period or frequency." Still another theory holds that the impulse follows those fibers which have the same chronaxies, that is, nerves which have the same excitation period.

It has been demonstrated that the degree of conductivity over the synapses may be changed or raised by repeating the stimulus at frequent intervals until a response is made. This may be the result of repeated stimuli on the receptor nerve endings; it is known as **summation of stimuli.** Something of the same mechanism may be responsible for the transmission of an impulse across the synapses. To illustrate, one might not withdraw his hand if pricked gently by a pin only once, but repeated gentle pricks might result in muscular action and withdrawal, or the appropriate reflex. Sometimes repeated stimulation will result in failure to respond, owing to **fatigue** of the neuromuscular mechanism. Sometimes, while response is being made to one stimulus, another stimulus may enter the "circuit," either from within (from the cerebrum) or by the action of another stimulus from without, and stop this reaction. This **inhibition** probably means that some synapses in the usual path of a nerve impulse have been blocked. For example, if the skin is pricked by a needle, the purely reflex response would result in muscular movement causing the hand to be automatically jerked away; but, if the cerebrum intervened, such a reaction might be **inhibited** or the entire body might be moved from the region of irritation rather than just the hand. Concentration on a problem or in carrying out a definite activity involves certain inhibitions or responses. The soldier in the midst of battle may be so "intent" on his objective that he fails to notice his wounds. The reaction or adjustment in the nervous system opposed to inhibition is known as **facilitation.** For example, if a person seated so that the leg hangs free is tapped below the knee cap, a prompt kick (knee jerk) will be the response. If, at the time the blow is struck, a sharp sound is made, the knee jerk will be more pronounced. Thus the original reflex is augmented by the second stimulus, producing facilitation. The cerebrum also may play a part in facilitation of certain responses.

Transmission paths. The following illustration may serve to give a clearer picture of the general facts just presented and the part they

play in the nervous system. Suppose that the foot is pricked by a needle and the reflex results in only a movement of the leg, owing to blocking at other synapses, which prevents the nerve impulse going up the spinal cord to higher levels. However, suppose that the conductivity of the synapses is increased; the impulse may now go on to a higher level of the cord or into the cerebellum. Other reflex paths of this level are opened and, in addition to the jerk of the foot, there may be head movements, an outcry, and perhaps increased respiration and pulse rate. These reactions are more complex and likely to be more varied. It is possible, if the stimulus is strong enough both in intensity and summation, that the nerve impulse may reach the cortex of the **cerebrum** or highest level where there is a complicated arrangement of neurons. Actions of the cerebrum are **conscious activities.** Here, as a follow-up to the reactions just described, the injured foot may be treated with mercurochrome or iodine. Only when the impulse reaches the cerebrum is the pain perceived. If the cerebrum were absent, the individual would not know the pin had pricked him. Nevertheless, the reactions governed by the spinal cord and the cerebellum would take place.

SOME GENERAL ASPECTS OF ANIMAL BEHAVIOR

We have already seen that tropistic responses as well as simple reflexes are automatic adjustments by the whole or parts of an organism reacting to a stimulus or change in its environment. The question is often asked, "Do animals, other than man, think?" "Do they have intelligence, or merely 'instinctive' behavior?" To answer these questions and to approach the problem of animal behavior with understanding, it would seem necessary to attempt to distinguish between "instinctive response" or behavior and intelligent response.

The problem of "instincts." In the preceding pages we have seen that the scientist attempts to analyze bodily activities such as digestion and circulation by obtaining experimental evidence based upon the working of actual structures which he can see and, to some extent, manipulate. It has been pointed out that, in the days before the application of scientific method and advancement of scientific knowledge, there was supposed to be some "vital principle" which was necessary for the functioning of the stomach and for the circulation of the blood. In fact, all matter which was found in the organism was set apart as organic matter, something different from the inorganic matter found outside the organism. When an investigator

could no longer explain an activity in terms of its demonstrable mechanical workings he resorted to this vital-principle idea. Today, psychologists are attempting to employ the scientific method of assembling objective evidence based on observation and experimentation, to explain all animal behavior including human behavior. In times past, and even today, when certain traits of animal behavior reach a point where they are no longer analyzable, there is a tendency to say that they are "instinctive," that is, that they are one of the peculiar properties of the animal. One psychologist collected reports of more than 5,000 of these supposedly instinctive patterns! The term instinct thus came to be regarded as the refuge of the psychologist when he could no longer explain behavior on the basis of observed mechanisms.

In the language of science today, the term instinct with its unscientific connotations is being viewed most critically, and it may soon be decisively discarded. The observable basis of unlearned behavior is designated as "unlearned trends" or "innate traits." Those who are opposed to the instinct idea and who believe that they are using the scientific method for the study of behavior are inclined to stress the reflexes, which can be more easily analyzed in terms of behavior. They maintain that unlearned trends must spring from an inherited bodily structure and are automatic. The activities of the organism represent the functioning of those physical structures. Given the appropriate stimulus, the animal automatically carries on the specific pattern of behavior.

However, as we shall see below, such automatic acts may be modified. It has been claimed that these so-called instincts, which are probably complex reflexes, are or have been useful in the preservation of the individual animal or the race at some time in its individual or racial history. This statement does not mean that the animal "knew" that any particular reaction was useful. It reacted because its reflex patterns were so blocked out. Confronted with an apparent old situation in a new environment, it makes the inherent response, even though this response may result in its death. Thus moths and many insects fly at night—the moths to get food from the light-colored or white flowers which are so conspicuous in the darkness. The eyes, nervous system, and wing muscles are so constructed that anything of a light color forces a movement toward it. If it is a flower, food is secured; if it is a light or a flame, death is the result.

Learning. Learning might be defined as a modification of behavior by reason of experience. The amount or degree of learning possible will depend upon the complexity of the nervous mechanism.

We have pointed out that the nervous system reaches its highest degree of complexity in man. It would logically follow that, if we find the most complex nervous system in man, here we will likewise find the most complex behavior pattern. By the same reasoning we should expect to find in the simplest animals the simplest adjustment mechanism and the simplest behavior patterns. For the lower animals and also for the higher animals, including man, two fundamental learning processes are recognized. They have been designated as learning by **trial and error** and learning by **conditioned response.**

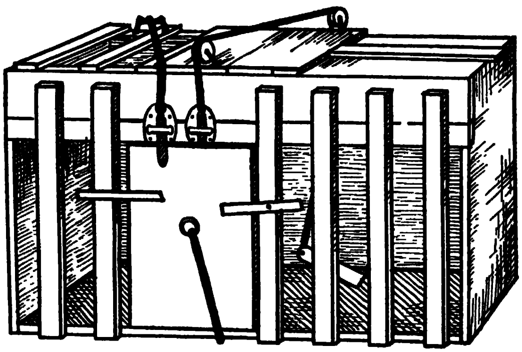


FIG. 131. Thorndike's box.

TRIAL AND ERROR. When an ameba, one of the simplest animal organisms, comes in contact with a drop of acid, it withdraws the pseudopodium; then on the same side of the body it puts out another pseudopodium which may come in contact with the same acid drop, only to withdraw the new pseudopodium. This behavior may be repeated several times. Finally pseudopodia project from another side of the animal and it sets out on a new course that leads away from the irritating medium. However, there is no evidence showing that the ameba ever learns to avoid acid or to make its adjustment by fewer random movements.

In one of his classic experiments devised to investigate the trial-and-error type of learning, Thorndike made use of what was known as the problem box (Fig. 131). In this box he would confine a hungry cat or dog and outside the box he placed some food. The box was so constructed that the animal could escape from it by pressing a lever, pulling a loop of cord, or stepping on a platform. When put into the box, the animal naturally would attempt to escape. It would claw and beat at the bars, or thrust its paws through any opening

it could reach. It would continue this thrashing about, striking anything loose and movable. In the course of this vigorous, persistent action, eventually and accidentally, the animal would strike the lever, or pull the loop of cord, or tip the platform, opening the way for its escape. This first release, as we see, was accomplished by **trial and error.** After the same animal had been subjected to the same set of conditions for a number of days, involving many trials, it would immediately claw the button or loop, thus securing a prompt release. It had learned. It is interesting to note that even after the loop had been removed the animal would paw the place where the loop had been.

The following selected experiment will emphasize trial-and-error learning and will show how widely the process of learning is distributed in the animal kingdom. Herrick describes the following interesting experiments by Yerkes with earthworms. Yerkes devised a "T-shaped passage with the entrance at the stem of the T and exit at the right hand turn. At the left turn he placed a piece of rough sandpaper, beyond which was a device for giving the worm a painful electric shock. After 20 to 100 experiences the worms **learned** to avoid the left turn and to go directly to the right and so escape." Heck later repeated the experiments and found that, if the front end of the worm containing the brain was removed, the worms, after growing a new head and brain, reacted as before. "Removal of the brain did not destroy the habit."

Another method common in trial-and-error experiments is the maze method, in which an animal is placed in a complicated system of unobstructed pathways and blind alleys through which it must learn to find its way from the starting point to the goal where food is placed for motivation. After a number of trials, the animal learns to make the right turns and to avoid blind alleys so that it reaches the food in a shorter period of time. Incidentally, this maze running is a habit-forming process. Alterations in the maze have caused the animal to change the habit. Consequently, we might say that a **habit** is a "mode of adjustment" capable of certain modifications to fit circumstances. Adaptations of the problem box and the maze have been used for human subjects as well as for rats, cats, and dogs.

CONDITIONED RESPONSE. It is known that, whenever food is taken into the "mouth" or buccal cavity, the saliva begins to flow. Apparently this is a natural reflex. About 1900, the Russian physiologist, Pavlov, measured the flow of saliva from the salivary gland of a dog by leading a salivary duct to the outside of the cheek and collecting the saliva there as fast as it was secreted. Pavlov noticed that the flow of saliva would begin, not when the dog had the food placed in its mouth, but when he saw the food or his food dish. The sight of the man who usually fed the dog would also start the secretion of saliva. Pavlov designated this response a **conditioned reflex;** by the elaboration of experimental procedures for the investigation of this

type of response, he made a real contribution to our study of animal learning.

Since, in a strict sense, this is not a reflex, it has been called more properly a **conditioned response.** In hopes of making further discoveries concerning such responses, Pavlov set up an experiment to "condition" the salivary response by more artificial stimulation. A hungry dog had food placed in his mouth at the time an electric bell began to ring. This procedure was repeated a number of times. Then the bell was rung before the food was offered, and it was found that the saliva began to flow at the sound of the bell. It was likewise discovered that, just as it was possible to develop a conditioned response by training, so was it also possible to eliminate it. Apparently it is safe to say that the nervous system is modified in some way in the conditioning just as it is in other kinds of learning.

When a minnow is thrown into an aquarium with a hungry perch it is promptly seized and devoured. A perch was confined in one end of a glass tank separated by a glass partition from the other end where there were some minnows. The perch tried repeatedly to get these minnows, only to dash vainly against the glass. After a time the attempts were abandoned. Later when the glass partition was removed the perch would swim freely around among the minnows and not attempt to eat them. This experiment not only illustrates **learning** and **memory** but shows us what is meant by a **conditioned response** and **association** as well. Another interesting feature of this experiment is the fact that the cerebrum of these fishes has no cerebral cortex, which in man is the supposed center of intelligence.

There are differences between the learning process of man and that of the other animals. Woodworth,* a psychologist, thus summarizes these main points of human superiority:

"1. Man is a better observer; he observes many characteristics of things, people and situations that lie beyond the animal's scope.

"2. Man uses more deliberation, management and control in attacking a problem.

"3. Man makes great use of names, numbers and in general of language in learning.

"4. Partly by aid of language, man is able to think about problems even when the materials are not before him. After struggling vainly with a puzzle, a subject has been known to reach a solution while lying in bed the next morning. Ideation, the thinking of things that are not present to the senses at the moment, is doubtless much more highly developed in man than in any other animal."

* Robert F. Woodworth, *Psychology*, Henry Holt and Company, New York, Fourth Edition, p. 318.

For a more complete and detailed analysis of the behavior of man and the higher vertebrates the reader is referred to various books on the related science of psychology.

Popular Misconceptions About the Nervous System

Phrenology. One of the "pseudopsychological gold bricks" which is still sold by "readers" is what is known as **phrenology,** or the reading of a person's character by feeling the bumps on his head. These fakers have mapped out the cranium into various regions where there are localized such traits as benevolence, destructiveness, firmness, and self-esteem. The right bump in the right region shows a particularly strong characteristic for the trait located at that place. Today we know that the skull is no true indicator of the shape or size of the brain. Some heads have more bone than others. Further, as Lashley has shown, there is no definite localization of function in the cerebrum except those cases involving "the functioning of definite sensory or motor areas in the body."

Brain size. Phrenologists also stress size of the brain as an index of intelligence, but intelligence depends upon the quality rather than the quantity of gray matter. By actual determination, the brains of prominent people were found to weigh an average of but 2 to 4 per cent more than those of inmates of the workhouses. Nor is the difference in brain weight any indication that in intelligence men are superior to women.

Convolutions and learning. Another popular mistaken notion is that as learning progresses there is a deepening of the grooves in the brain resulting in more curves and more convolutions. This morphological change does not take place.

SUMMARY

One of the fundamental characteristics of protoplasm is its irritability or capacity to respond to stimuli, whether external or internal, and to make adjustments. A stimulus is any change in the external or internal environment of the organism causing changes in adjustment. This involves correlations in the organism, some of which are known as chemical and others as nervous correlations.

The simplest type of adjustment, known as a tropism or taxis, is found in all plants and many of the lower animals. As a matter of fact, almost all plant responses are tropistic. In the higher animals the response becomes more complicated and involved. Various mechanisms of adjustment are developed, resulting in well-defined systems and specializations of receptors, adjustors, and effectors. Receptors are such mechanisms as the eye, ear, and taste buds. Adjustors are systems of neuromuscular cells, neurons, and neural groups and their processes in the form of a nervous system. Effector mechanisms are muscles, bones, cilia, and the like, which, under the

dominance of the nervous system, bring about the necessary adjustments as a response to a nervous impulse. This receptor-adjustor-effector set-up results in a complicated system of reflexes and conditioned behavior. If conditioned by habit formation, memory, and other modifications, it results in learning, which reaches its highest development in man.

CHAPTER X

HOW DO LIVING ORGANISMS GROW AND REPRODUCE? GROWTH AND REPRODUCTION

In our study of living organisms we have now become familiar with the fact that living protoplasm whether found in animals or plants exhibits certain characteristics. These characteristics are revealed in the various activities of the organism and are responsible for its form, structure, and behavior. Thus we observe that all organisms, according to the species, present a rather uniform pattern or shape, develop a particular type of organization, carry on metabolism, eliminate waste, are irritable and capable of response or adjustment. We shall see that this same general similarity between the protoplasm of plants and that of animals is also manifested in their growth and reproduction.

GROWTH

In the living organism growth may take place by increase in the volume of the individual cells. The increase in the volume of the cell may be the direct result of an overabundant supply of food plus certain metabolic processes within the cells. We realize that life is a puzzling complex of physical and chemical processes by which the protoplasm and its components are being continually changed. Theoretically these changes result in the formation of increasingly complex substances that, being less active chemically, accumulate within the cell and so increase its volume.

Growth of the organism is a complex physiological activity observed by everyone, but so many factors and processes are involved that no one understands it fully. We have already learned that plant-cell elongation takes place only in the presence of auxins, and it is also postulated that cell division is induced by hormone action. We may ultimately discover that all coordinated development or growth of cells, tissues, and organs is controlled by hormonal influences.

One of the most obvious phases of growth is enlargement, which is a result of the increase either in volume of individual cells or in

number of cells or in both. If we observe an individual cell under favorable conditions we may see it undergo a division, forming two new cells. Assuming a generally spherical shape of the cell, we may find a reason for its division in the unbalanced relation between its surface and volume. Inasmuch as the volume of a sphere increases as the cube of its diameter (d^3) whereas the surface increases only as the square of the diameter (d^2), we can appreciate the fact that the volume of the growing cell increases much more rapidly than its surface. It must be evident that, since oxygen and all essential nutritive materials are taken into the cell through its surface membrane and wastes are eliminated by the same means, increase in size will eventually reach a limit where the surface membrane can no longer transmit materials in amounts sufficient to meet the requirements of the total volume of protoplasm. The change of ratio causes a protoplasmic response resulting in cell division and the restoration in the daughter cells of a favorable ratio between cell surface and cell volume. This adjustment emphasizes once more the fact that all protoplasmic activity is largely a struggle to maintain a state of equilibrium with an ever-changing environment.

Cell division. Mitosis. The separation of an actively growing cell into two daughter cells generally takes place by an indirect cell division called **mitosis.** Since mitosis is involved in the growth and reproduction of all plants and animals, we should become familiar with it. There are numerous variations in the details of mitotic cell division, but no attempt will be made to present them here. However, a general picture of the process will enable us to appreciate its significance in cell multiplication, reproduction, and inheritance (Fig. 132).

We recall that imbedded in the cytoplasm of the cell lies the nucleus, consisting of nuclear sap and chromatin, surrounded by a nuclear membrane. When the cell is in the resting state, i.e., when it is not involved in preparations for division, the chromatin of the nucleus is so distributed as to form a network (Fig. 13). Within the cytoplasm, lying close to the nuclear membrane, is a very small protoplasmic entity called the **central body.** In the activity preparatory for division, the central body divides, and each one of the new bodies formed becomes surrounded by a group of radiating fibers called collectively an **aster** (*aster*—star). The central body and aster do not appear in the cells of higher plants, but in all other respects mitosis in these organisms is essentially the same as in animals. These new central bodies, with their asters, now move apart until they come to lie at opposite poles of the nucleus. At the same

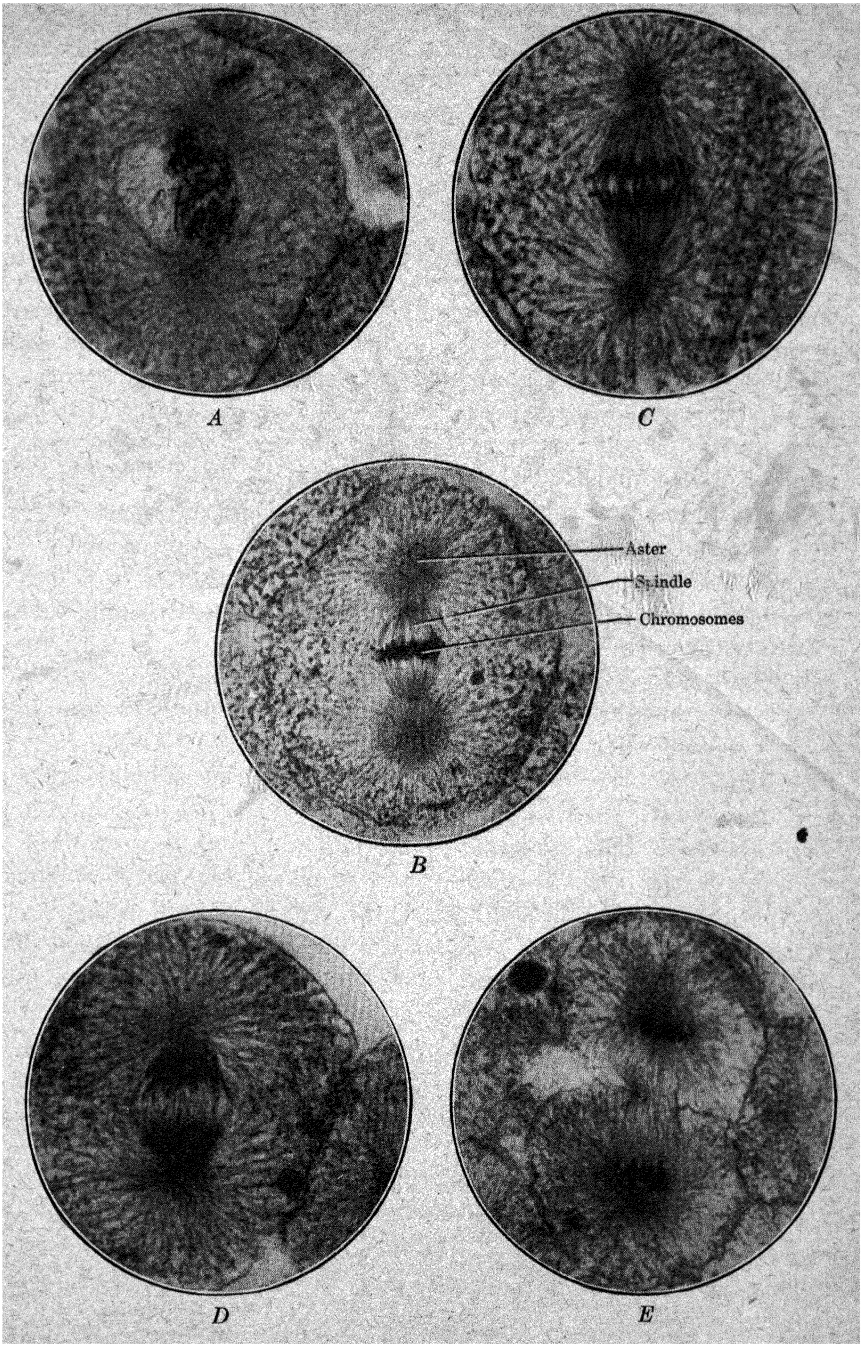


FIG. 132. Photomicrographs showing stages in mitosis. *A*, late prophase. *B*, metaphase. *C*, early anaphase. *D*, later anaphase. *E*, telophase. *Photomicrographs furnished by the General Biological Supply House.*

time, the nuclear membrane gradually disappears and a **spindle** made up of fibers connects the two asters. During this period of cytoplasmic activity, the chromatin network resolves itself into a single thread, the **spireme** (*speirema*—a coil). Very early in its appearance, this thread is seen to be split into two equal halves. Toward the close of this first stage **(prophase)** of mitotic activity, parts of the spireme begin to assume the form of double **chromosomes** (*chromos*—color; *soma*—body). A chromosome is a mass of chromatin. The number of chromosomes in the body cells of any particular species is constant. Thus in the cells of man and tobacco there are 48 chromosomes, whereas in those of the lily there are 24 chromosomes.

In the next stage **(metaphase),** these double chromosomes come to lie at least in part at the central region of the spindle, where they are assembled in a plane, lying perpendicular to the long axis of the spindle, known as the **equatorial plane.** Although of very short duration, the metaphase is an all-important stage in mitosis, for here each of the double chromosomes becomes completely separated into longitudinal halves that are precisely alike both quantitatively and qualitatively. The halves of each pair now begin to move apart and finally come to lie at opposite ends of the spindle. This stage is known as **anaphase** (*ana*—up). As a result of this migration of the chromosomes, each central body is now associated with a complete set of chromosomes, the two sets being exactly alike.

The organization of two new nuclei constitutes the final mitotic stage known as **telophase** (*telos*—end). The chromosomes become vacuolated, and the chromatin material is so arranged that the chromatin network characteristic of the resting nucleus again appears within a new nuclear membrane. About the time the daughter chromosomes arrive at the ends of the spindle, a change takes place in the region of the equatorial plane which results in the complete division of cytoplasm of the original cell so that two new cells are formed. These new cells may now undergo further structural changes that will build them into working units of the particular tissue of which they form a part.

Thus we see that in all growth certain initial steps are involved. A cell ordinarily grows until it reaches a certain size, when it divides and gives rise to new cells. These processes may go on indefinitely. Finally, after a new cell is formed, it undergoes such changes as are inherently necessary in adapting it for its own peculiar work. Cell enlargement, cell division, and cell differentiation are therefore the initial steps in all growth.

Amitosis. The separation of a cell into two daughter cells may take place by direct cell division, known as **amitosis** (*a*—not; *mitos* —a thread). In amitosis the nucleus develops a constriction that finally pinches it into two separate portions. The cytoplasm may or may not be separated in a similar manner. This kind of cell division occurs mainly in old tissues and in abnormal or diseased tissues. It apparently plays no important role in the reproduction of higher organisms.

Cancer. Cancer and tumors have been known since ancient times, and they are widely distributed throughout the animal and plant kingdoms and among all races of men. Cancer now claims 160,000 persons annually in the United States. Cancer and tumors are abnormal growths initiated by a single abnormal cell or group of such cells which, for some unknown reason, grow and multiply at a tremendous rate. This cell multiplication takes place by direct cell division and usually not by mitosis. The abnormal growths may affect any part of the body. They are of no use to the organism, are beyond its control, and apparently have no stopping point. Of the growths mentioned there are two types, known respectively as benign and malignant. Benign tumors never spread and are restricted in their growth by a limiting membrane. In the malignant type, usually thought of as "cancer," the abnormal cells are carried through the body by the blood stream, by the lymph channels, by growth from tissue to tissue, and by distribution through the coelom.

The actual cause of cancer is not known, but chronic irritations such as those caused by a pipe on the lip, irritation of the cheek from a broken or rough tooth, and chronic irritations from chemicals and from physical agents such as light and X-rays seem to be predisposing factors. There is no evidence that cancer is a germ disease or that it is contagious, nor has it been demonstrated that diet will tend either to initiate or to cure cancer.

Cancer can be cured if treatment is begun at an early stage. Medical authorities urge that periodic physical "check-ups" be made and that there should be an immediate visit to a reputable physician when any of the following symptoms are observed:

1. Any persistent lump or thickening, especially of the breast.
2. Any irregular bleeding or discharge from any of the body openings.
3. Any sore that does not heal, particularly about the tongue, mouth, or lips.
4. Persistent indigestion, especially when accompanied by distaste for meat.

5. Persistent hoarseness which lasts for a month or longer.
6. Sudden changes in the form or rate of growth of a mole or wart.
7. Pain is usually a late symptom—do not wait for it.

The cures for cancer are radium and X-ray, either alone or in combination, or surgery. People are urged to beware of "sure fire" cancer cures by "secret methods."

REPRODUCTION IN PLANTS

As has been stated previously there are two kinds of reproduction: asexual and sexual. In asexual reproduction there is a division of the organism, and each part formed in this way is capable of giving rise to a new individual. In sexual reproduction there is a fusion of two special reproductive cells to form a new cell which ultimately gives rise to a new individual. Although these two types of reproduction occur in both plants and animals, asexual reproduction is much more general and far more important in plants.

Asexual Reproduction in Plants

In simple one-celled plants, an ordinary vegetative cell divides into two nearly equal daughter cells each of which may grow into a new individual. This method of asexual reproduction is called **simple fission** (*fissio*—a dividing) (Fig. 133). In such reproductive activity the parent disappears, but its substance and life are continued in the life of its progeny. In the unicellular yeast plant, a small protuberance grows out from the cell and is later cut off by a constriction. This newly formed minute cell may remain attached to the parent cell for some time, increasing in size until it becomes as large as or sometimes even larger than the old cell. Sooner or later this new cell may divide in the same way, giving rise to one or more new individuals. New cells formed in this manner are called **buds,** and this type of asexual reproduction is known as **budding** or **gemmation** (*gemma*—bud). Multicellular bodies called **gemmas** are produced by some of the simpler plants. When they are detached they may grow at once into new plants (Fig. 133). In many plants a portion of the body becoming detached in some way may continue to grow and thus give rise to a new individual. Such asexual reproduction is known as **vegetative reproduction.** A number of plants exhibit this type of reproduction almost exclusively.

The Irish potato, sweet potato, sugar cane, pineapple, and certain varieties of onions are crop plants that are propagated solely by vegetative reproduction. Other plants, such as horseradish, produce very few or no seeds and therefore can be propagated only vegetatively. Many horticultural varieties—our favorite apples, cherries, peaches, and grapes—do not "come true" from seeds, and therefore vegetative propagation is the only way in which the variety can be preserved. Underground stems are used almost exclusively in the vegetative propagation of lilies, tulips, hyacinths, irises, cannas, chrysanthemums, and many other kinds of ornamental plants. In propagating the Irish potato, tubers are used, but roots are employed for the propagation of the sweet potato.

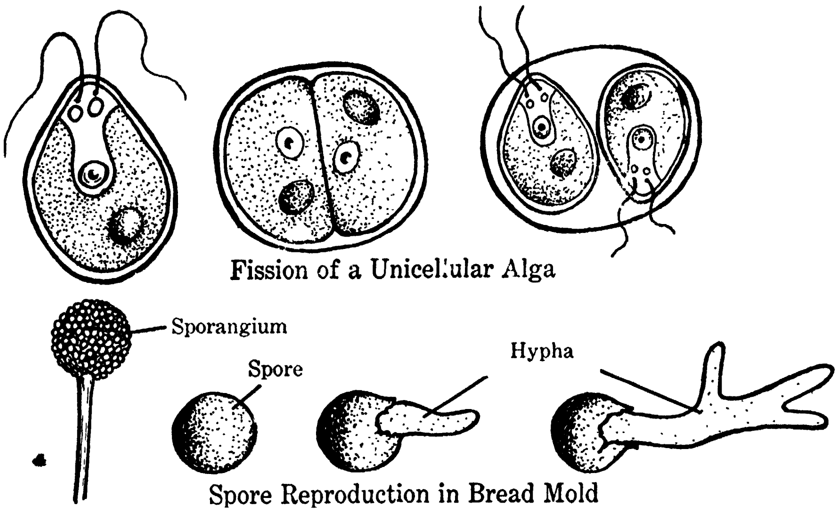


FIG. 133. Asexual reproduction in the simplest plants.

Roses and grapes are very frequently propagated by **layering.** A branch of the mother plant is bent to the ground and covered with soil at a point some distance from the tip. Roots form at this point, and when the branch is detached it may be transplanted to some other place. Geranium, coleus, begonia, and other herbaceous plants are propagated by means of **cuttings,** often called "slips." A cutting is a piece of stem containing several nodes. Either a few attached leaves must be present or a supply of stored food sufficient to provide energy for growth until new leaves are formed. Cuttings are generally propagated in greenhouses and hotbeds under glass. Most of the leaves are removed to prevent excessive transpiration, and the cuttings are planted in sand kept constantly moist. *Begonia* and *Bryophyllum* may be propagated by leaf cuttings. Whole leaves or parts of leaves, when placed in moist soil, give rise to new plants (Fig. 134). In the wartime construction of hundreds of airfields in the southern portion of the United States, thousands of acres of land were planted with Bermuda grass to provide control of dust and erosion. The grass was established by sprigging, that is by planting fragments of stolons and rhizomes.

Many woody plants may also be propagated by cuttings, usually selected in late fall or early winter when the wood is dormant. The cuttings are then tied up in bundles of 25 or more and buried in a trench with the uppermost

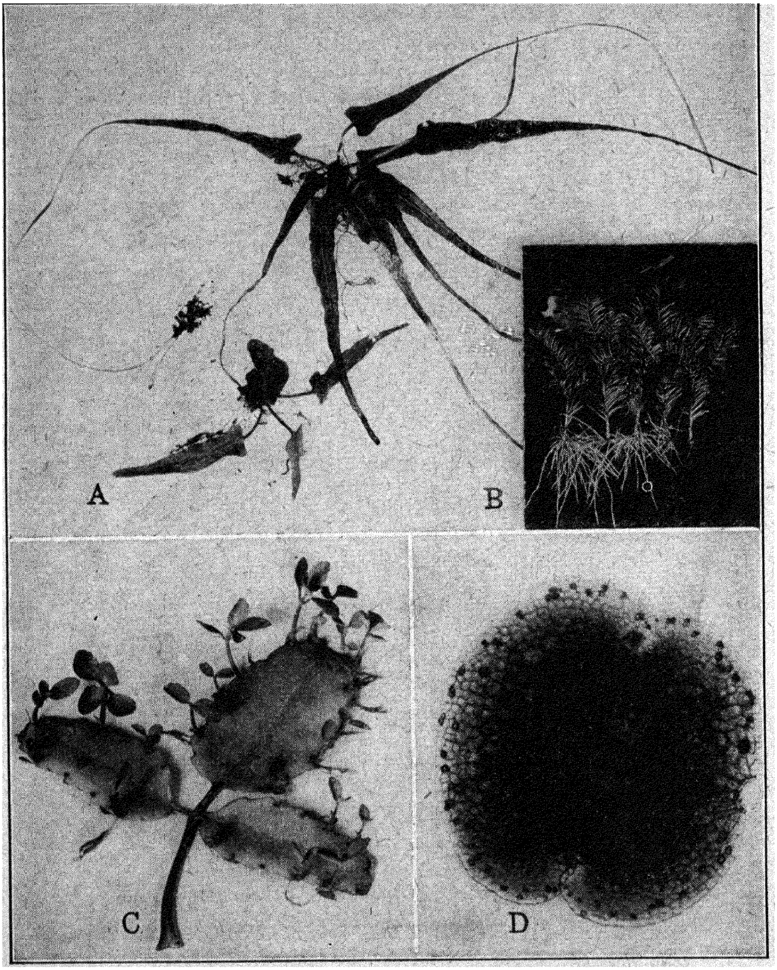


Fig. 134. *A,* development of young fern plants from the tips of the leaves of a walking fern. *B,* cuttings of yew. *C,* development of new plants on the margins of leaves of bryophyllum. *D,* gemma of liverwort. *Photograph A, furnished by the New York Botanical Garden; B, by John M. Arthur; C and D, by H. Lee Dean.*

buds turned downward. Sometimes the cuttings are planted in sand and kept over winter in cool cellars. In the spring they are planted 3 or 4 inches apart with only the topmost ends protruding from the soil. The purpose of the previous winter treatment is to encourage the formation of a **callus** at the

lower end of each cutting, for in the spring the first roots develop from this callus tissue.

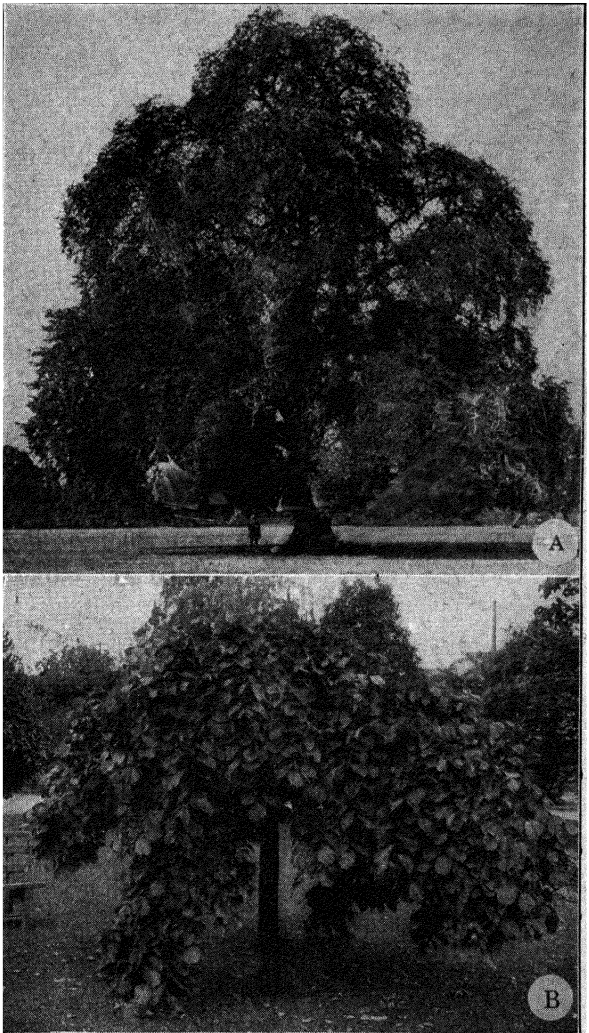


FIG. 135. *A*, a typical Scotch elm (*Ulmus glabra*). *B*, a top-worked Scotch elm, known as the Camperdown elm. *A, furnished by Arnold Arboretum, Harvard University; B, by J. Horace McFarland.*

Grafting and **budding** are employed to propagate seedless varieties of plants, or hybrid plants whose seeds will not "come true," i.e., will not give rise to plants like the parents. European varieties of grapes are seriously injured and often destroyed by the attacks of a species of root louse. This parasite does not feed upon the roots of American grapes, and consequently the grape growers

of Europe have checked the ravages of the insect by grafting their plants upon the root systems of American grapes. Grafting (top-working) is used to control the shape of some plants such as the umbrella catalpa, weeping mulberry, and Camperdown elm (Fig. 135). It should be emphasized that new plants cannot be produced by grafting.

In grafting, a twig called the **scion** is cut from a tree of the desired variety and inserted in a cleft made in the stem, called the **stock,** of some less-desirable

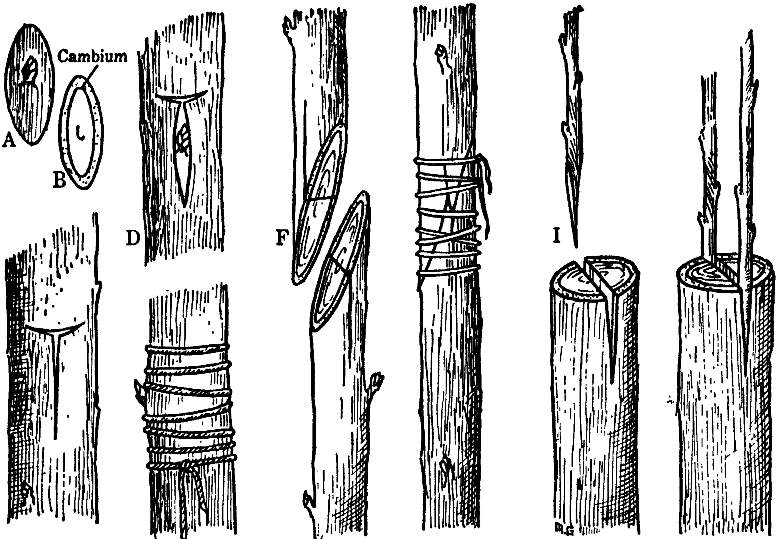


FIG. 136. Budding and grafting. *A* and *B*, front and back views of a bud removed from the twig. *C*, the T-shaped incision made for the reception of the bud. *D*, the bud placed in proper position beneath the bark. *E*, the bud firmly tied in its proper position for growth. *F–G*, method of cutting scion and stock employed in whip grafting. *H*, the completed whip graft. *I–J*, method of cutting scion and stock employed in cleft grafting. *K*, completed cleft graft.

variety in such a manner that the cambiums of scion and stock are in close contact (Fig. 136). The stock and scion are then bound together to keep the scion in the proper position. The junction is sealed with grafting wax to prevent desiccation and the entrance of bacteria or other foreign organisms. In the course of time the new cells developed in the cambiums of scion and stock form a close union, and the scion begins to grow into a new tree or a branch, depending upon where the graft was made. Budding is done in much the same way except that a bud is used instead of a twig. The base of the bud is inserted beneath the bark on the side of the stem. Thus we see that in both grafting and budding cuttings are used, but they are planted into another plant and not in the ground. If grafting and budding are to be successful, the scion and stock must be chosen from plants that are rather closely related. One may graft apples and pears, tomatoes and potatoes, artichoke and sunflower, but one cannot graft successfully apples on cherries or peaches on oaks. Plants must

be chosen which have a cambium, since it is this tissue in scion and stock that grows to form an intimate union. It is always desirable to bring into contact as much cambium as possible in order that a firm and permanent union may be formed.

Spores. Finally, asexual reproduction is effected by means of **spores,** which vary widely according to the plants by which they are produced. In some of the simpler plants, "resting" spores are common. They are ordinary vegetative cells which have become gorged with food and covered by a much-thickened protective wall. The spores usually form at the approach of unfavorable conditions, and their protective features enable them to survive through periods of low temperature or drought when all the other cells may be killed. When favorable conditions are restored the protoplast swells, ruptures its thick wall, and grows into a new vegetative plant. In other lower plants an ordinary vegetative cell gives rise by division to **zoospores** (*zoon*—animal; *sporos*—seed) (Fig. 137). These are naked, motile, flagellate protoplasts. The **flagella** (*flagellum*—whip) are protoplasmic projections that serve as organs of locomotion. When the zoospores are mature they escape through an opening in the cell wall, swim about freely for a time, and finally settle down and become attached to a suitable substratum, where they grow into new individuals. In many plants there is formed a special spore-producing organ called a **sporangium** (*sporos*—seed; *aggion*—a receptacle). In most of the fungi, bread mold for example, and in land plants generally, the spores produced are very small and light, and thus well adapted for air dispersal. The term spore includes such a great variety of structures that it is difficult to give any satisfactory definition.

Sexual Reproduction in Plants

Among the lower plants there is a simple plant called *Spirogyra* whose cells are arranged end to end in a very delicate thread or filament (Fig. 137). In the reproduction of *Spirogyra,* the cells of two filaments lying side by side become connected by outgrowths that fuse to form **connecting tubes.** The protoplast of one cell now flows through a connecting tube into the cell of the other filament, where the two protoplasts unite to form a new cell. A thick wall develops about this new cell which, after a period of rest, grows into a new individual. In another of these simple filamentous plants, called *Ulothrix,* the protoplasts of ordinary vegetative cells divide a number of times, forming small bodies, each of which is provided

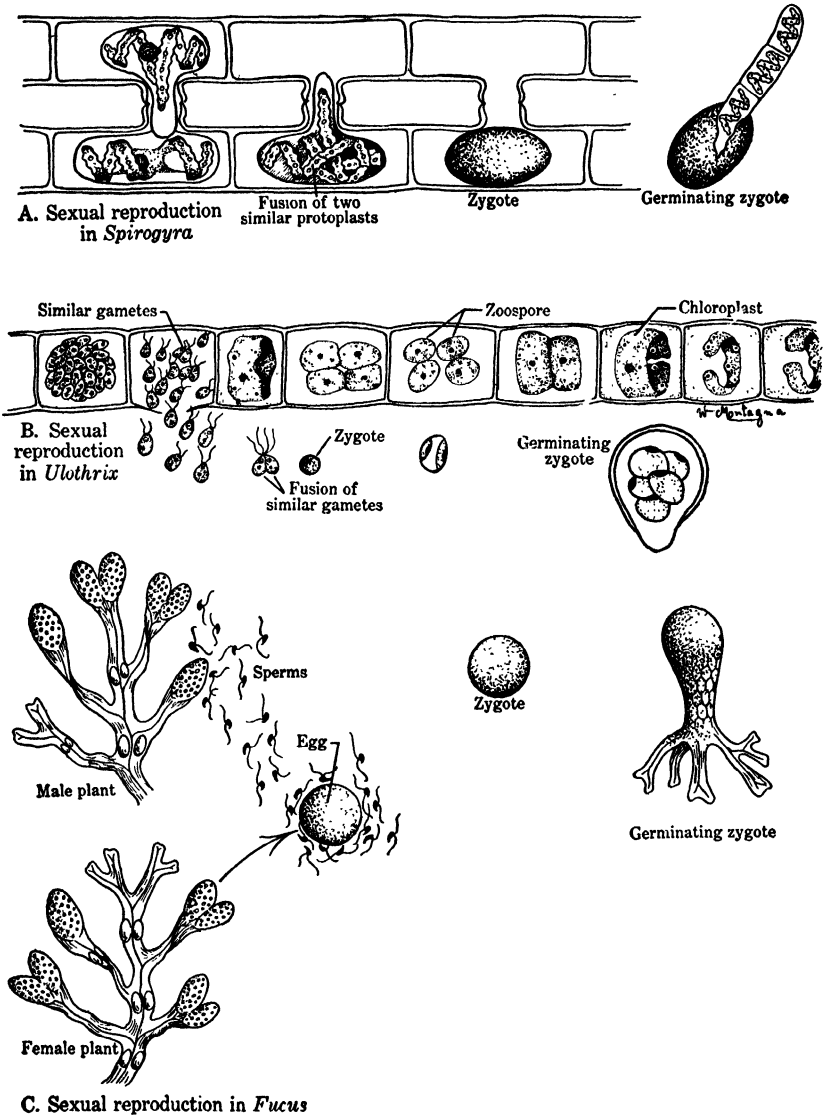


FIG. 137. Progressive development of sexual reproduction in plants. From the fusion of similar protoplasts of vegetative cells in *Spirogyra* (*A*) and the appearance of similar gametes in *Ulothrix* (*B*), the development finally reaches an advanced stage in *Fucus* (*C*) in which there are two types of gametes, sex organs, and sex individuals.

with two flagella (Fig. 137). Eventually, the cell wall breaks and these little bodies swim out into the water, where two of them may come together and fuse. This process is very similar to the union of the protoplasts of *Spirogyra* except that in *Ulothrix* the uniting cells are more specialized and provided with organs of locomotion. The new cell resulting from the fusion ultimately undergoes a series of divisions that give rise to a number of zoospores, which may grow into new individuals.

The tiny flagellate protoplasts produced in the cells of *Ulothrix* are called **sex cells** or **gametes** (*gamein*—to marry), and the cell formed by the fusion of two of these gametes is known as a **zygote** (*zygotes*—yoked). In both *Ulothrix* and *Spirogyra* all the gametes produced are visibly alike. Sexual reproduction effected by like gametes is called **isogamy** (*isos*—same). If we select a plant somewhat higher in the scale of development, such as the seaweed *Fucus*, we shall discover two kinds of gametes: large, non-motile ones, in which there is a rich supply of food materials; and smaller, motile cells similar to the gametes of *Ulothrix* (Fig. 137). While swimming about, one of these small gametes may come in contact with one of the large gametes and fuse with it to form a zygote. Sexual reproduction involving the fusion of very dissimilar gametes is called **heterogamy** (*heteros*—other or different). The small gametes are **sperms,** and the larger non-motile gametes are **eggs** or **ova.** The fusion of these gametes is known as **fertilization.**

Thus we see that sexual reproduction involves the production of small specialized cells called gametes which fuse to form a zygote. The zygote has the potentialities necessary to produce a new individual. It divides and subdivides, forming many cells that grow and differentiate, each to perform its specific task in the life of the new organism of which it is an integral part. The essential features of this process occur not only in the higher plants but in animals as well. In order that we may become familiar with the details of sexual reproduction as it occurs in some well-known plant let us follow the process in some such plant as the lily, the bean, or the plum. We have seen that the vegetative organs of the plant, viz., leaf, stem, and root, are made up of tissues and structural differentiations that function coordinately in carrying on the life processes of the organism. Now we shall find a similar coordination of functions in those specialized organs of the plant that are concerned primarily in reproduction, viz., the **flower, fruit,** and **seed.**

Structure of the flower. A common flower such as a plum blossom is made conspicuous by a circle of five white, leaflike structures called

petals (*petalon*—leaf). Outside this ring of petals is another circle of five leaflike structures, often green in color, called **sepals** (*skepe*—a covering) (Figs. 138 and 142). The ring of petals is known as the **corolla** (diminutive of *corona*—crown), and the circle of sepals is called the **calyx** (*calyx*—husk). Calyx and corolla together form the floral envelopes or **perianth** (*peri*—around; *anthos*—flower). Just inside the perianth is a circular cluster of slender, stalklike structures, each bearing a knob at its free end. These are the **stamens** (*stamen*—warp or thread). The knob is known as the **anther,** and the threadlike stalk is the **filament** (*filum*—thread). Inside the mature anther are very small spherical bodies called **pollen grains** (*pollen*—fine dust) or **microspores** (*micros*—small; *sporos*—seed). Within the circle of stamens, at the very cente of the flower, is a structure that looks somewhat like a miniature ten-pin (Figs. 138 and 142). This structure is called the **pistil.** The enlarged base of the pistil is known as the **ovary** (*ovarium* from *ovum*—egg), and it is prolonged upward in a slender structure called the **style.** At the summit of the style is a specialized region, often somewhat enlarged, called the **stigma.** The pistil is made up of one or more component parts called **carpels** (*karpos*—fruit). If there are two or more carpels, they may be entirely separate or more or less united. Carpels, stamens, petals, and sepals represent modified leaves borne on a common stem apex called the **receptacle.** If the ovary is cut open, little chambers called **locules** (*locus*—place) are exposed. If the pistil consists of but one carpel, only one locule will be present. For two or more carpels there may be as many locules, but in some such pistils the separating carpel walls disappear and then the locules are merged into one. Within the locules are very tiny spherical bodies called **ovules** (*ovum*—egg) borne on a ridge of specialized tissue called the **placenta.** A microscopic examination of the ovule reveals that it is a small body of tissue, the **nucellus,** covered with two layers known respectively as the **inner** and **outer integument** (*integumentum*—a covering). At the free end of the ovule there is an opening in the integuments known as the **micropyle** (*micros*—small; *pila*—gate). Within the ovule, at a certain stage in its development, four **megaspores** (*mega*—large) are formed, only one of which functions. The functional megaspore develops into a structure containing eight nuclei called the **embryo sac.** The nuclei separate into two groups of four each, one group lying at either pole of the embryo sac; hence they are called **polar nuclei.** Then one nucleus from each polar group migrates to the center of the sac, where they may fuse to form the so-called **fusion nucleus** or they may remain separate. One of

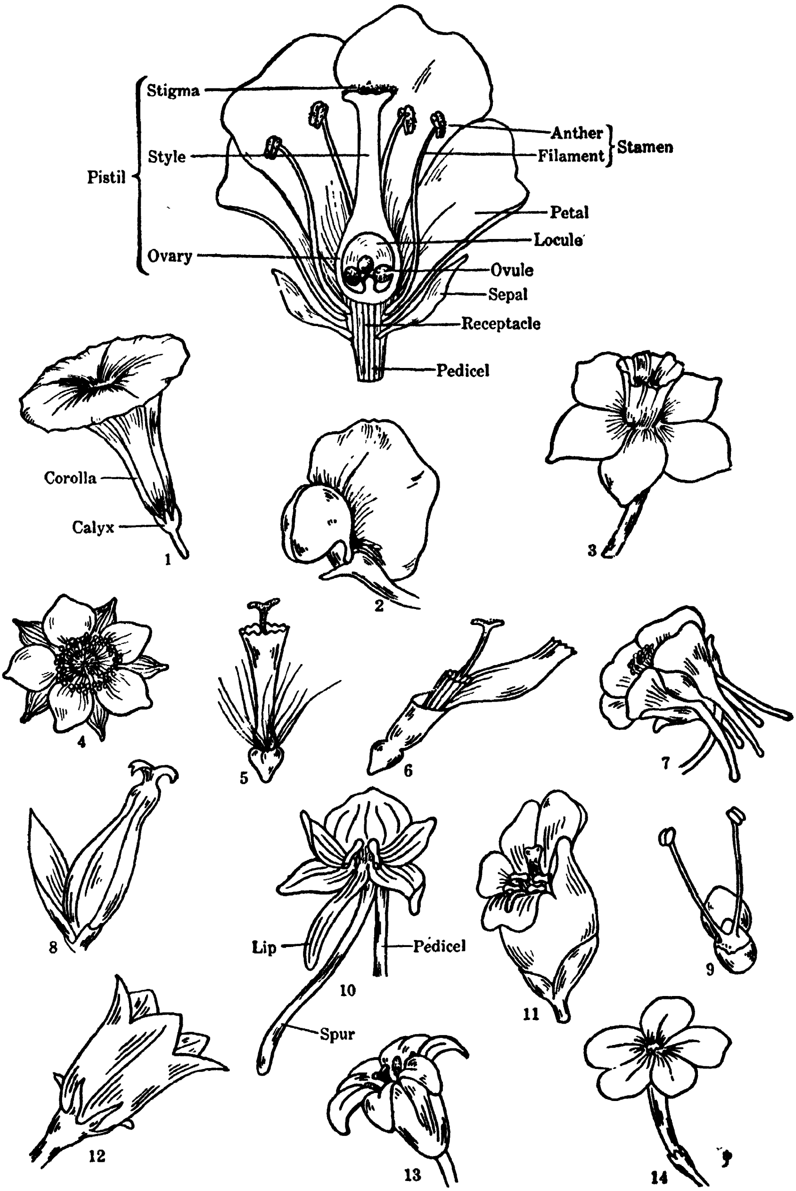


FIG. 138. Structure of the flower and various types of flowers: (1) funnel-form flower of morning glory; (2) irregular butterfly-like flower of sweet pea; (3) crowned flower of *Narcissus;* (4) flowering raspberry; (5) tubular flower of a composite; (6) ligulate flower of a composite; (7) spurred flower of a columbine; (8) pistillate and (9) staminate flowers of willow; (10) spurred flower of an orchid; (11) irregular flower of figwort; (12) campanulate flower of bluebell; (13) fawn lily with recurved petals; (14) salver-form flower of phlox.

the remaining nuclei at the end of the sac nearest the micropyle becomes the **egg nucleus** or the **female gamete,** and the two others, one on either side of the egg nucleus, are the **synergid nuclei** (*synergos*—working together). The three nuclei, known as **antipodal nuclei,** remaining at the opposite end of the sac disintegrate and disappear. The embryo sac has now attained its mature form.

There are, of course, many deviations from the structure of the flower as described above, and some of them will be discussed later. Some flowers have stamens but no pistils—**staminate flowers**—and others have pistils but no stamens—**pistillate flowers.** When a plant bears both stamens and pistils in the same flower, or in different flowers, it is said to be **monoecious** (*monos*—one; *oikos*—household). If staminate and pistillate flowers are borne on separate plants, the plants are termed **dioecious** (*di*—two; *oikos*). So far as reproduction is concerned, the really essential parts of the flower are the stamens and pistils. In fact, we shall now focus our attention on the pollen grains and the ovules as the all-important agents in the reproductive activity of these plants.

Pollination. The mature pollen is carried from the anther to the stigma of a pistil by various agents such as wind, water, birds, insects, man, and gravity. The transfer of pollen from anther to stigma is called **pollination.** When pollen grains produced by one flower develop on the stigma of the same flower, or on the stigmas of other flowers on the same plant, we speak of the process as **self-pollination.** If, on the other hand, the pollen of one flower develops on the stigma of a flower on another plant, we call it **cross-pollination.** Cross-pollination is far more common than self-pollination, which occurs in wheat, oats, tobacco, and some other plants. In some plants either or both kinds of pollination may occur, and there is no apparent advantage in either the one or the other. However, in many plants, self-pollination is ineffective or results in poor seeds which produce less vigorous offspring. In such plants there have appeared in the pattern and structure of flowers numerous adaptations which seem to be definitely related to cross-pollination. Correlated adaptations appear in insects, and it is believed that these adaptations of flowers and insects, from their very beginning, have been mutually stimulative and mutually beneficial.

Adaptations insuring cross-pollination. The most successful method of insuring cross-pollination is the development of staminate flowers on one plant and pistillate flowers on another, as in willows and poplars (Fig. 139). In some species the pollen grains will not germinate on the stigma of the same flower. In certain flowers the

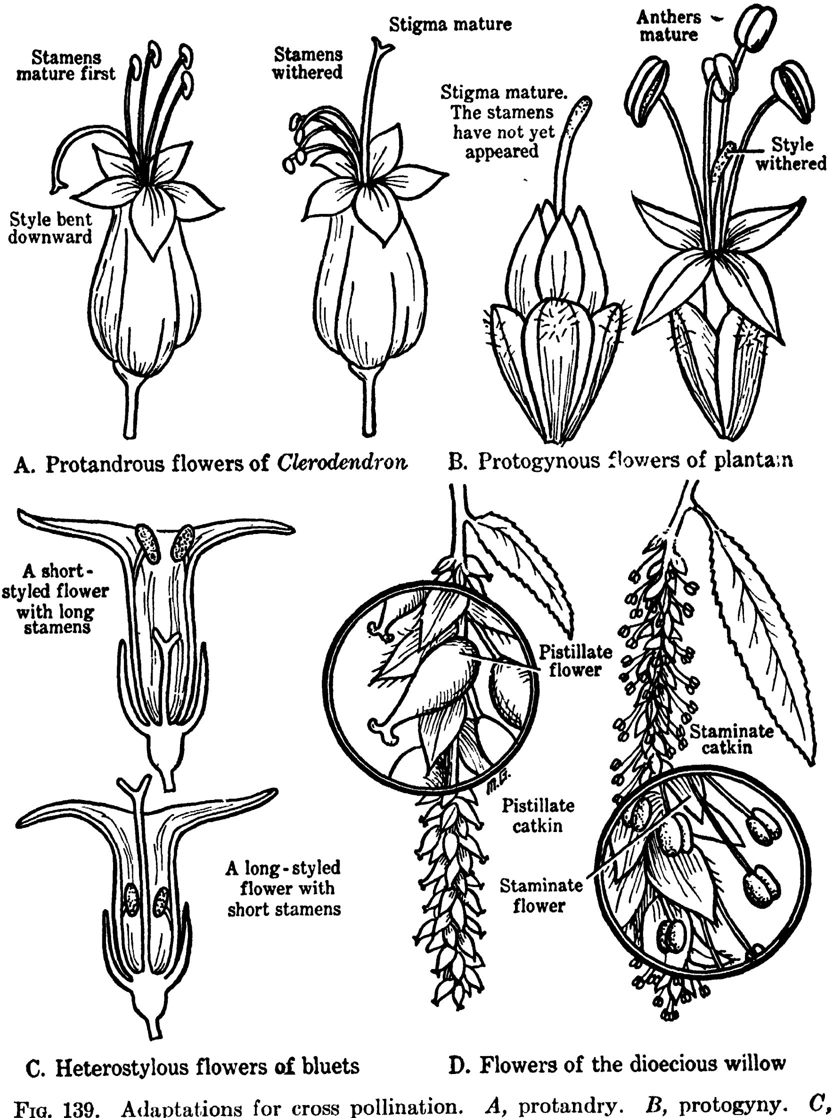


FIG. 139. Adaptations for cross pollination. *A,* protandry. *B,* protogyny. *C,* heterostyly. *D,* staminate and pistillate flowers on separate plants. *Drawn by Grace Boggess.*

anthers and stigmas of the same flower mature at different times so that the stigma is not receptive when the pollen is being discharged. This is called **dichogamy** (*dicho*—in two or asunder; *gamos*—marriage). Dichogamy may be complete, but more often some overlapping occurs, permitting some self-pollination.

In bluets and primroses some of the flowers have long styles and short stamens, and others have short styles and long stamens (Fig. 139). In the long-styled flowers the stigma stands at almost the same level as the anthers of the short-styled flowers; likewise in the short-styled flowers the stigma is on practically the same level with the anthers of the long-styled flowers. This condition is known as **heterostyly** (*heteros*—other or different). An insect that happens to visit one form of these flowers will receive pollen on a part of its body that is most likely to touch the stigma of the other form of flower when it is visited by the insect. It has been demonstrated that in these plants a much larger amount of good seed is produced when pollen from low stamens comes in contact with low stigmas, or when pollen from high stamens reaches the high stigmas.

Insect-visited flowers are usually bright colored and fragrant. They also produce a sweet secretion called nectar, which with the pollen furnishes food for the insects. Sometimes, as in the orchid, the flower has a protruding petal or lip which serves as a landing place for the insect, and the nectar collects in a sac or spur (Fig. 138). In the milkweed and orchid the pollen grains are held together by a delicate membrane, and the entire mass **(pollinium)** is carried away by the insect. In the flower of the common barberry the stamens are so sensitive that when an insect alights in the flower they spring up suddenly, showering the under surface of the insect with pollen grains. There is almost an endless array of such adaptive arrangements and mechanisms, and a similar list is given by the entomologist in his description of insects and their relation to flowers.

Much has been written concerning the relative importance of color and odor in attracting insects to flowers. It is very doubtful that the colors recognized by us also affect the eye of the insect. Odor probably attracts insects to some extent, although we have little dependable knowledge concerning this matter. Certain flowers that have the color and the odor of carrion are visited by flies, especially carrion flies, but whether this is accidental or whether these insects are really attracted by the odor is as yet an unsolved problem. Memory and habit may be far more important than odor and color as aids to insects in their visitation of flowers. Flowers are quite commonly grouped in clusters of various kinds and patterns. This grouping of flowers **(inflorescence)** makes it possible for an insect to visit a much larger number of flowers in a given time and doubtless insures a greater percentage of pollinated stigmas (Fig. 140).

Flowers of *Yucca* are pollinated by a small white moth (Fig. 141). The bell-shaped flower has a long style ending in a cuplike depression lined by the stigmatic surface. Pollen falling from the stamens does not reach the stigma because the style extends downward in the hanging flower. In the evening, a

female moth visits one of these flowers, collects some pollen from the anthers, and carries it to another flower. Here she thrusts her ovipositor into the ovary, lays some eggs, and then crawls down the style and pushes the wad of pollen into the hollow stigma. These pollen grains germinate, and as a result the ovules develop into seeds. The eggs of the moth produce larvae that feed upon

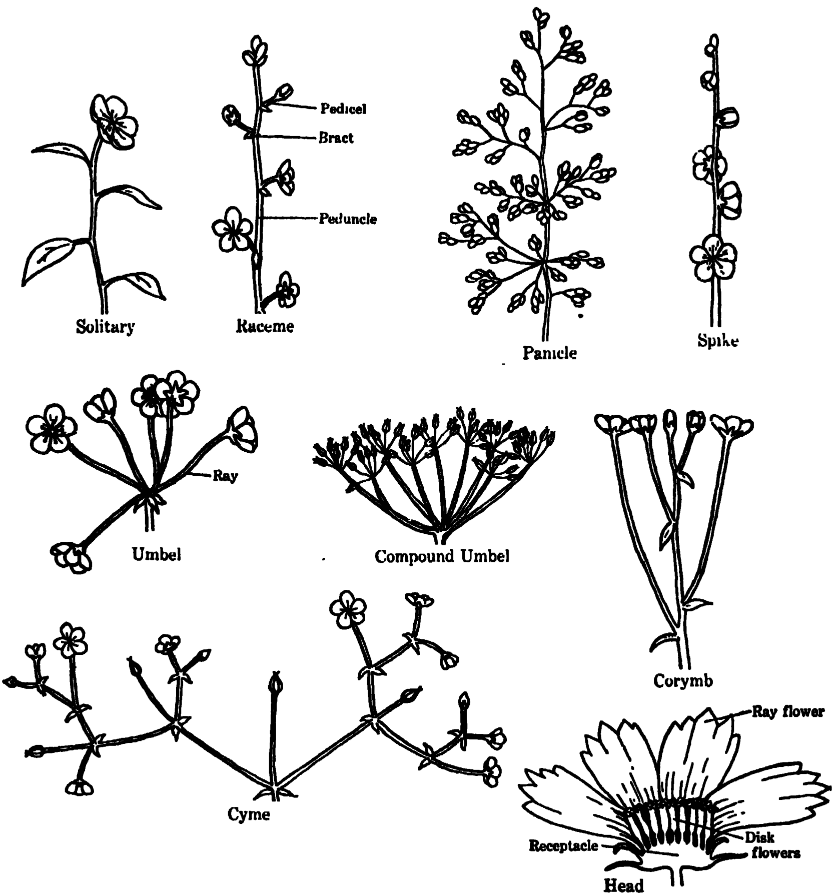


FIG. 140. Types of inflorescences. *Drawn by Grace Boggess.*

the seeds. But only some of the seeds are destroyed; a goodly number remain to propagate the race. Without the moth no seed would be produced, and without the seed of the *Yucca* the larvae would have no food. This is a most interesting relationship, the origin of which remains a baffling question.

The fig furnishes the classic, and an extremely fascinating, example of cross-pollination by insects (Fig. 141). Here pollination is effected by a wasp. The tiny flowers of the fig are produced in great numbers inside a hollow receptacle which has a small opening at one end. The receptacles that will later develop into commercial figs contain only pistillate flowers with long styles. Other

receptacles known as **caprifigs,** borne on other plants, contain staminate flowers and pistillate flowers with short styles. These short-styled flowers are called gall flowers. When a female wasp enters a caprifig she lays her eggs in the ovaries of these gall flowers. Unable to escape she finally dies within the caprifig. The eggs hatch, and the young feed upon the tissues of the gall flowers.

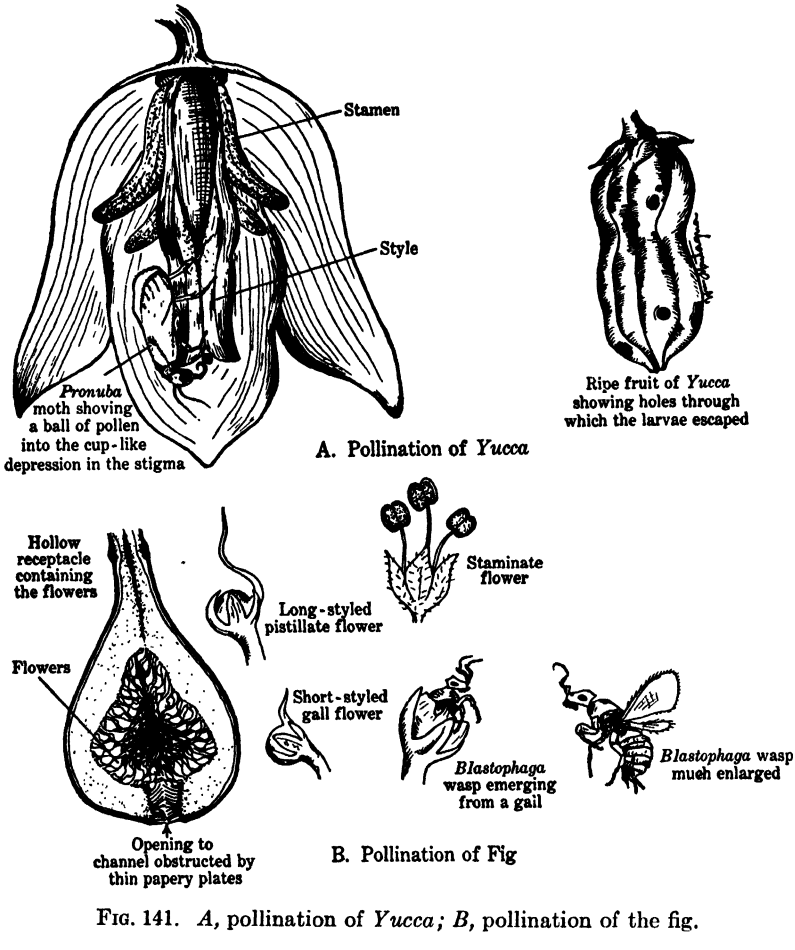


FIG. 141. *A,* pollination of *Yucca; B,* pollination of the fig.

When the males have matured they eat their way out of the ovaries and, in the same way, they enter the ovaries containing females. Mating takes place, after which the males die. The females now leave the ovaries in which they were hatched and, in crawling about over the staminate flowers, become thoroughly dusted with pollen. They crawl to the opening in the caprifig and, passing through it, fly to another receptacle. If perchance one of these females now visits one of the receptacles (figs) with the long-styled flowers, she will force an entrance but with such difficulty that she may lose her wings in the process. Once inside, she crawls over the flowers hunting for a place to deposit

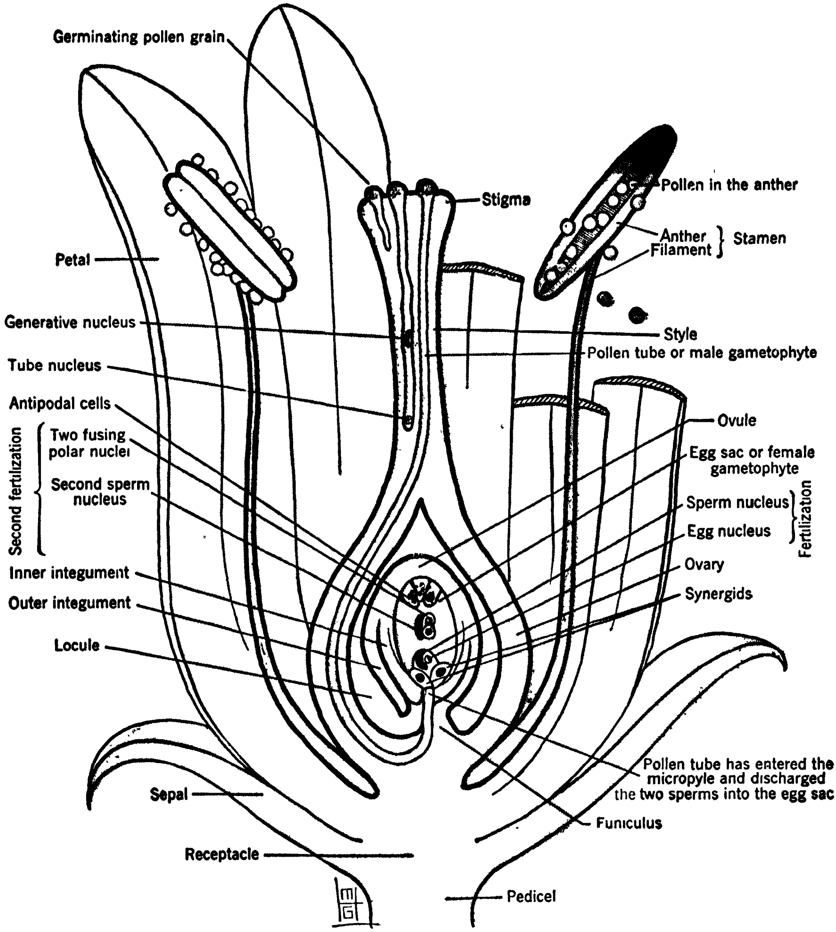


FIG. 142. Diagram of sagittal section of a flower showing gametophytes and fertilization.

her eggs, and while doing this she rubs the pollen from her body onto the stigmas. However, the long styles make it impossible for her to reach the ovaries with her ovipositor, and so she can lay no eggs. She is likewise unable to make her way out of this receptacle, which therefore becomes her tomb. The wasp perishes, but the flowers, having been pollinated by her, develop seeds, and the receptacle ultimately becomes a fig.

Fertilization. When a mature pollen grain reaches the stigma it germinates; i.e., it grows. Moisture passing through the coat of the pollen grain causes it to swell until finally the outer layer is ruptured. The protoplast then begins to penetrate the tissue of the stigma and style and elongates into a tube known as the **pollen tube** (Fig. 142). The protoplasm of the pollen tube secretes enzymes that digest the cells of the tissues in the style, and thus it may be said to eat its way through the style. It gets its energy for growth from this digested material and continues to elongate until finally the tip enters the micropyle of the ovule. In the mature pollen grain there are two nuclei, a **tube nucleus** and a **generative nucleus.** The tube nucleus comes to lie in the tip of the pollen tube and apparently regulates its growth. The generative nucleus divides into two nuclei that function as **sperms** or **male gametes.** These sperm nuclei pass down through the pollen tube and eventually are discharged into the embryo sac, where one unites with the egg nucleus and the other with the fusion nucleus, or with the two polar nuclei if they have not fused. The tube nucleus disappears. Thus we see that a sperm nucleus unites with an egg nucleus to give rise to a zygote from which there will arise a new plant.

Development of the seed and embryonic plant. When the second sperm unites with the fusion nucleus or the two polar nuclei, the resultant body is called the **endosperm nucleus.** This immediately begins a series of divisions that give rise to a tissue known as the **endosperm** (*endo*—within; *sperma*—seed). The cells of this tissue become gorged with food materials which are later used by the embryo plant. The zygote also initiates a series of divisions, and the new cells produced organize themselves to form an embryonic plant with three distinct regions: the **cotyledons** or "seed leaves"; the **hypocotyl,** in the lower end of which the meristem of the primary root develops; and the **plumule,** which gives rise to the stem and leaves (Figs. 143 and 144). While the embryo is developing, enlargement of the ovule, together with thickening and structural modifications of the integuments, transforms the whole structure into a **seed.** Therefore a seed is a fully matured ovule containing an embryo. Ordinarily, fertilization is necessary for the formation of an embryo,

but in the dandelion and some other plants the unfertilized egg gives rise to an embryo. This process is known as **parthenogenesis** (*parthenos*—virgin; *gen*—beginning).

Fate of the endosperm. In some seeds **(albuminous seeds)**, such as the castor bean, the cotyledons remain thin, delicate structures and the embryo is more or less crowded in the seed by accumulated endosperm. In other seeds **(exalbuminous seeds)**, such as the com-

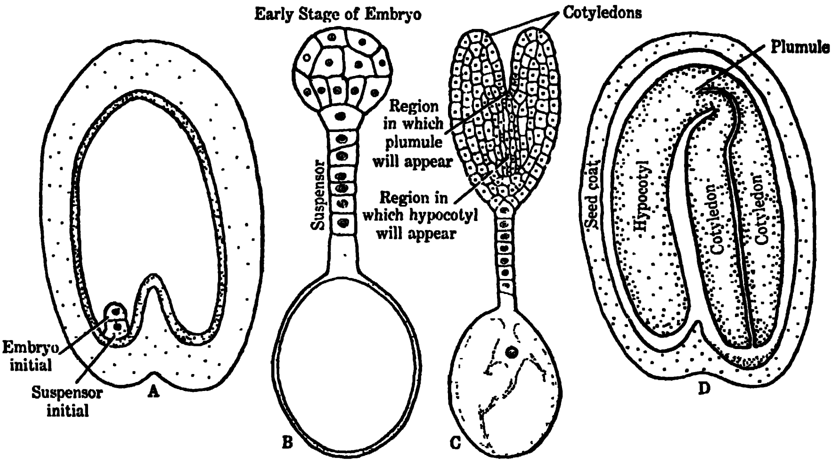


FIG. 143. Four stages in the development of the embryo of shepherd's-purse (*Capsella bursa-pastoris*). *A* shows first division of the zygote forming the embryo initial and the suspensor initial. *B*, *C*, and *D* show progressively more advanced stages. *D*, an embryo plant, fills the space within the seed coats. *Drawn by Grace Boggess.*

mon garden bean, the embryo devours all the endosperm and stores the food reserves in its cotyledons, which become thickened and so much enlarged that they make up most of the bulk of the seed. The hard covering of the seed, called the **testa** (*testa*—a shell), is derived from the integuments of the ovule. Nearly all seeds, after the embryo is formed, become dormant; i.e., no further growth takes place for a greater or less period of time, depending upon the species of the plant.

Seed dispersal. The scattering or dispersal of seeds is a very important factor in the propagation of a species. It is accomplished in many different ways (Fig. 145). Some seeds are borne by winged fruits that are carried considerable distances by air currents. The seed of the common milkweed develops a plumelike appendage and is thus easily carried by the wind. Palatable fruits are eaten by

various animals, and the indigestible seeds are thus accidentally transported, especially by birds, to regions quite remote from the place of their origin. Seeds and fruits alike are often provided with hooked spines or barbs that cling tenaciously to the coats of animals and the clothing of men, and are thus widely dispersed. Seeds of

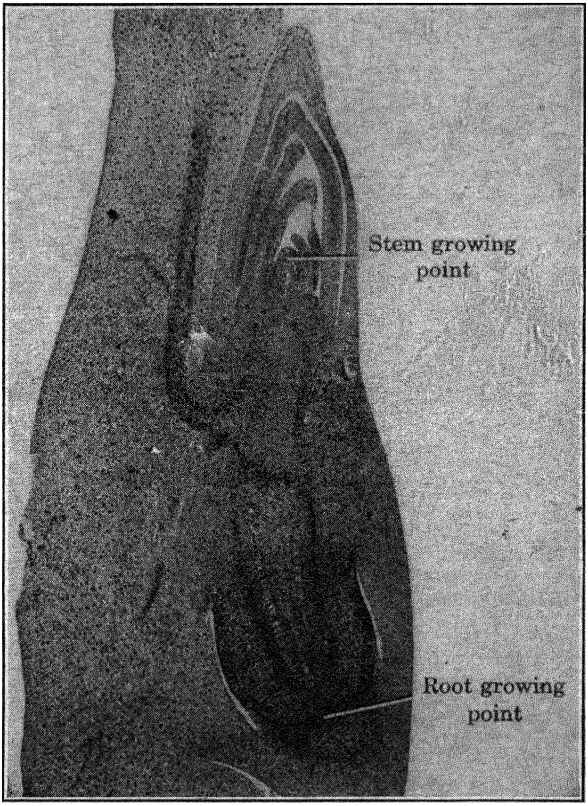


FIG. 144. Photomicrograph of the embryo of a monocotyledon. *By permission of the General Biological Supply House.*

water plants imbedded in the mud, adhering to the feet of wading birds, are often carried great distances during the migratory flights of these animals.

Fruits. While the seed has been developing, marked changes have been taking place in the ovary or some of its accessory parts or both. These changes are so variable in different species that we can merely mention a few by way of illustration (Fig. 146). Regardless of the nature or extent of the changes made, the ovary is transformed into a

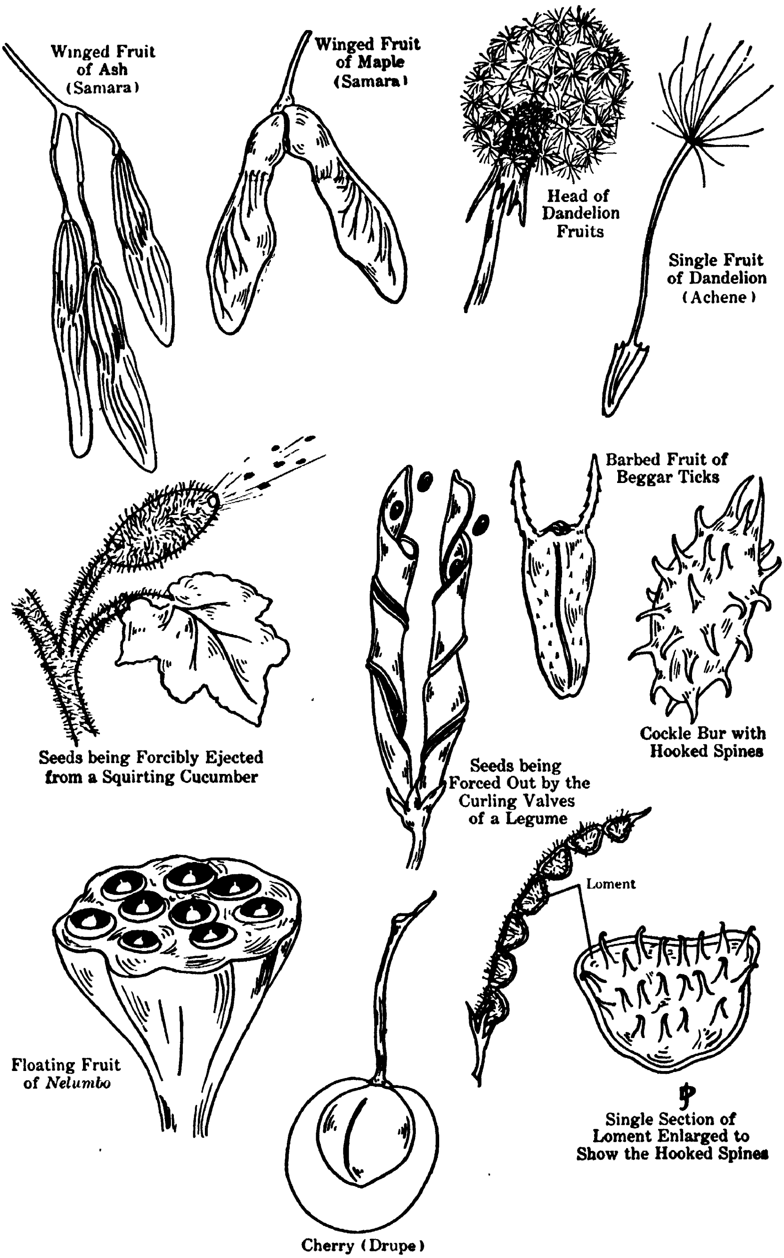


FIG. 145. Various modifications of fruits that aid in seed dispersal.

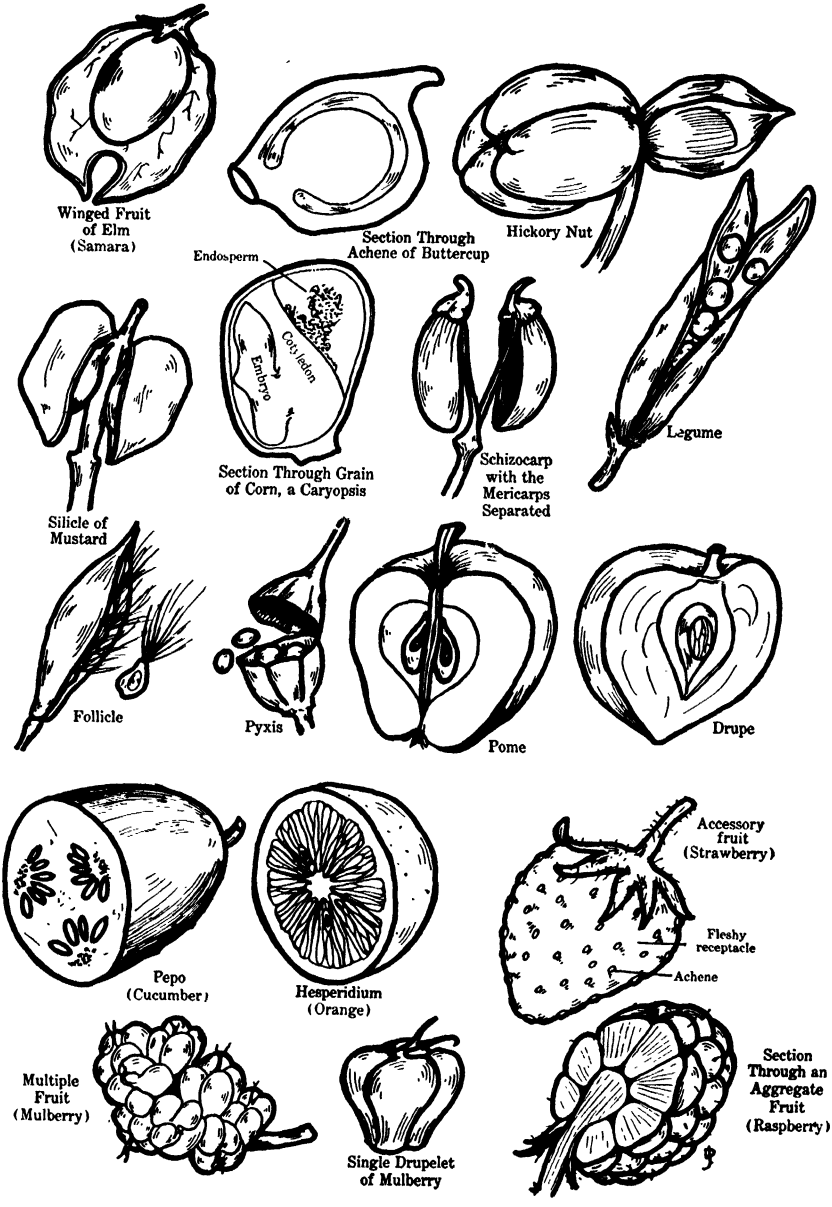


FIG. 146. Types of fruits.

fruit, and whatever its structure, the fruit is primarily advantageous in helping to disseminate the seeds. In apples, pears, and quinces the receptacle grows up around the ovary and forms the pulpy, edible part of the fruit. The ovary with its seeds forms the core. Such a fruit is called a **pome.** In a grain of wheat the ovary wall is coalesced with the seed coat, inside which a large mass of endosperm and a small embryo are crowded into one end of the seed. Such a fruit is known as a **caryopsis** or grain. The pistil may be made up of one or several carpels. In the bean the single carpel, greatly enlarged and dry when mature, contains a single row of seeds (beans) which are discharged from the carpel when it splits lengthwise along both sides, forming two halves **(valves).** Such a fruit is a **legume.** In the plum, peach, and cherry, the ovary wall becomes differentiated into three layers in the fruit: an outer layer called the rind, a middle layer that is pulpy and juicy, and an inner layer that is hard and stony. Within the stony layer is the seed, commonly called the "kernel." Such a fruit is known as a **drupe.** Fruits in which the entire ovary becomes pulpy, like the grape, tomato, currant, and date, are called **berries.** Generally, though not always, seed formation is a stimulus necessary for fruit development. No seeds are formed in the banana and the navel orange. Fruit formation without the development of ovules into seeds is known as **parthenocarpy** (*parthenos*—virgin; *karpos*—fruit).

To the average person a fruit is something good to eat, but this is not always the case. According to the interpretation of the botanists a fruit is a fully matured ovary with any accessory parts that may be involved. This definition includes such structures as Spanish needles and burs as well as apples and oranges. Even edible "fruits" may be derived from various structures. Thus the pineapple represents a whole cluster of closely set flowers in which the receptacle and flower parts become fleshy and succulent, forming a palatable "fruit." When we eat a pineapple we are eating a bunch of flowers and the stem on which they are borne. The luscious strawberry is a greatly enlarged, fleshy, juicy receptacle over the surface of which the ripened ovaries (real fruits called **achenes**) are scattered. Thus when we eat strawberries we are eating stems or fodder. Pumpkin, squash, melons, and cucumbers are modified forms of the berry, and such a fruit is called a **pepo.** So we must believe that when the farmer harvests his crop of pumpkins or melons he is gathering berries. The citrus fruits (oranges, lemons, grapefruit, tangerines) represent another kind of berry called the **hesperidium** (Fig. 146). This fruit has a tough outer rind packed with oil glands, and the juicy pulp consists of closely set tufts of fleshy hairs in which there is a rich storage of sugar, organic acids, and essential oils. Therefore, repulsive as it may sound, when we eat those delicious "Sunkist" oranges from sunny California, we are eating succulent plant hairs.

Development of the embryo plant. Germination. When the period of dormancy has ended, a seed placed in favorable conditions will germinate; i.e., it will begin to grow. However, considerable growth has already taken place in the development of the embryo from the zygote. So in germination the embryo merely resumes growth and develops into the seedling. Factors necessary for this resumption of growth are moisture, proper temperature, and aeration. The hard, protective seed coat (testa) first imbibes water. Then, the swelling of the embryo induced by water entering its cells ruptures the seed coat. In such seeds as bean and squash the cotyledons are lifted out of the ground and become green when exposed to light. Thus they assume for a time the role of photosynthetic organs, but when the true leaves appear, the cotyledons may soon shrivel and die. In the corn and the garden pea, the cotyledons remain in the soil, where they serve as organs for the digestion of the food reserves stored in the endosperm (Fig. 147). The hypocotyl emerges from the seed coats first and, in response to the stimulus of gravity, turns downward (positive geotropism) and immediately gives rise to the primary root. Structurally the plumule is a little bud whose embryonic leaves begin to enlarge and whose internodes begin to elongate as soon as the embryo is exposed, thus beginning the aerial parts of the plant. As soon as the new plant has developed a functional root system and an adequate food-manufacturing system, it has reached the seedling stage and a state of independence. This makes possible further growth and development into a mature individual capable of producing flowers, fruits, seeds, and another generation of plants.

An examination of different seeds and a study of their methods of germination soon reveal that some embryos have but one cotyledon while others have two. In our previous study of stems and leaves we noted some fundamental structural differences between the plants that develop from these two kinds of embryos. Therefore, this difference in the number of cotyledons forms a basis for the separation of flowering plants (angiosperms) into two main groups. Those plants in which the embryos have only one cotyledon are called monocotyledons, and those with two cotyledons are called dicotyledons.

Historical. Until well toward the close of the seventeenth century, sexuality in plants remained a moot question, and some very fantastic notions concerning reproduction of plants were recorded in the literature. The first really authoritative statement on the subject appears in a letter on the sex of plants, written by Rudolph Jacob Camerarius (1665–1721) in 1694. In this letter he discussed the

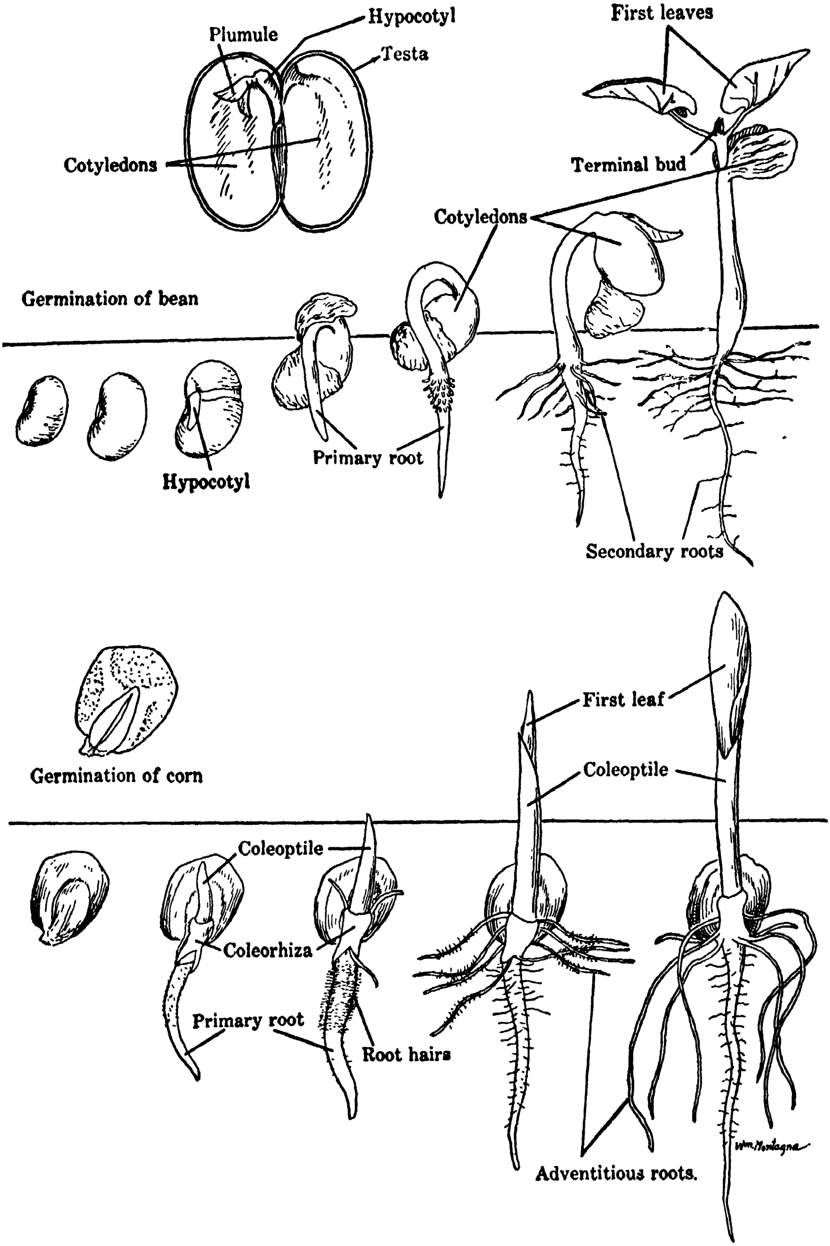


FIG. 147. Germination and development of the seedling. *Above*, a dicotyledon; *below*, a monocotyledon. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

ideas of the ancient authors concerning reproduction of plants and the different parts of flowers. He asserted that the pollen is male and the ovary female, and he described his experiments to prove his theory of the sexual behavior of plants. He planted a considerable number of both monoecious and dioecious plants and, by removing the male flowers, he demonstrated the inability of the female flowers to form fruit. However, when he provided these pistillate flowers with pollen, fruit was produced. All his experiments were planned and carried out with such care and precision that they have met all the requirements of the scientist of modern times, and to Camerarius credit is given for having proved the existence of sex in plants. Although many of his contemporaries refused to accept his conclusions, before the close of the next century his views were universally adopted.

REPRODUCTION IN ANIMALS

We have seen that plants may reproduce their own kind both asexually and sexually. In sexual reproduction germ cells called gametes unite to form a zygote, the beginning of a new individual. Animals likewise may reproduce either asexually or sexually.

Asexual Reproduction

Asexual reproduction requires but one parent for the production of new generations. By this method offspring may arise by fission, by budding, and by sporulation.

Fission. In fission the body of an animal divides into two parts, each of which in time forms an animal like the parent (Fig. 148). The ameba apparently pulls apart by constriction, as does also the paramecium. In the little flatworm *Planaria,* the posterior region of the animal constricts off; this is **transverse fission.** Some animals may split lengthwise in **longitudinal fission.**

Budding. In animals this is a process which very closely resembles budding in plants. A protuberance (bud) grows out of the parent animal and comes to resemble the parent in form and, in some instances, even in size. Usually this bud eventually separates from the parent animal and takes up a free existence. Sometimes "home ties" are too strong, and quite a few of the buds, with their buds, may remain attached to the parent. Thus a **colony** is formed. Various protozoans, sponges, hydras, and other animals higher in the scale show budding. Some animals produce internal buds, which in sponges are called **gemmules** (*gemmula*—little bud). If the parent

sponge dies, the gemmules remain where their parents were attached. Sometimes they are picked up with mud on the feet or the beaks of water birds and transported to new watery fields. Whether in the

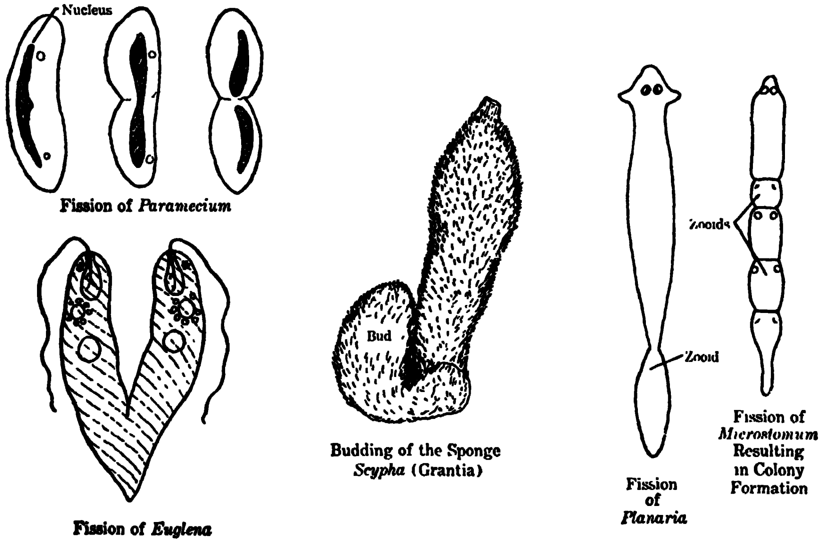


FIG. 148. Asexual reproduction in animals.

new habitat or in the old, when favorable conditions of temperature and moisture come, they grow into new sponges.

Spores and cysts. Spores are often formed by animals, particularly the Protozoa. In fact one large group of these animals employs spore formation so regularly in reproduction that it has been named the *Sporozoa* (*sporos*—seed; *zoon*—animal). Spores are often formed by the repeated divisions of the adult animal and somewhat

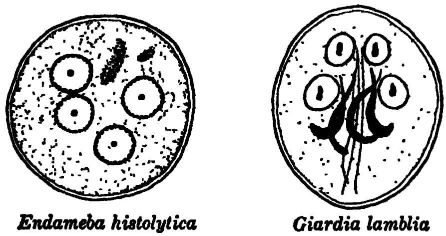


FIG. 149. Cysts of protozoan parasites.

less frequently by divisions of the zygote. The process of cyst formation or **encystment** consists in the production by the animal of an enveloping, somewhat hard gelatinous case which is protective against ordinary extremes of temperature and resistant to drying (Fig. 149).

The animal's metabolic rate or rate of living is greatly reduced, and thus life can remain in the dormant animal over a long period of time, or until environmental conditions become favorable once more for normal animal life. When ponds and brooks dry up many of the microscopic organisms form cysts and live through the adverse conditions. When such environmental conditions as water and temperature once more become favorable the cyst wall breaks and the animal again takes up its active existence. This process undoubtedly had much to do with the belief in the theory of spontaneous generation.

Regeneration

Some animals have the capacity to replace lost parts, a process called **regeneration** (*re*—again; *generare*—to beget). Some years

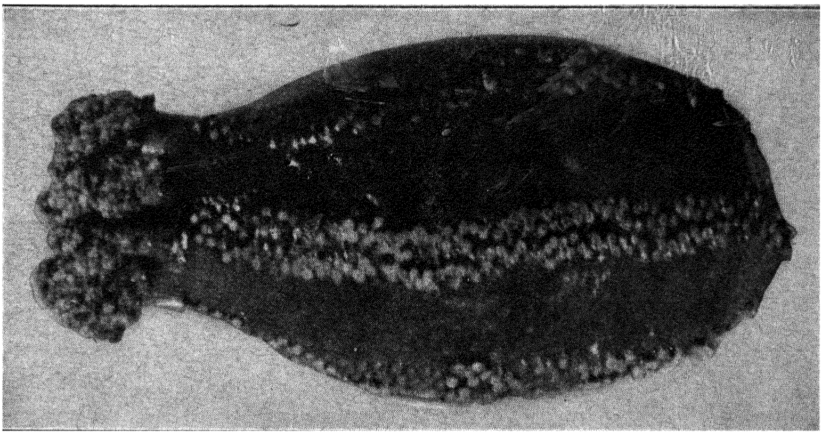


Fig. 150. Sea cucumber. *Photograph by David Huntsberger.*

ago oyster fishermen began to collect the starfish from their oyster beds, for they had found that man was not the only animal fond of oysters. They attempted to kill the starfish by chopping them into pieces. Then they shoveled the pieces overboard, where many of them grew into new starfish by regenerating the missing parts. This may be regarded as reproduction by fragmentation. A relative of the starfish, the sea cucumber (Fig. 150), when attacked by an enemy, will often extrude some of its internal organs. In some species there is also extruded a substance which swells up in sea water forming a mass of tough threads in which the enemy may be entangled. "A lobster has been rendered perfectly helpless as a consequence of rashly interfering with a sea cucumber." When danger is past, the

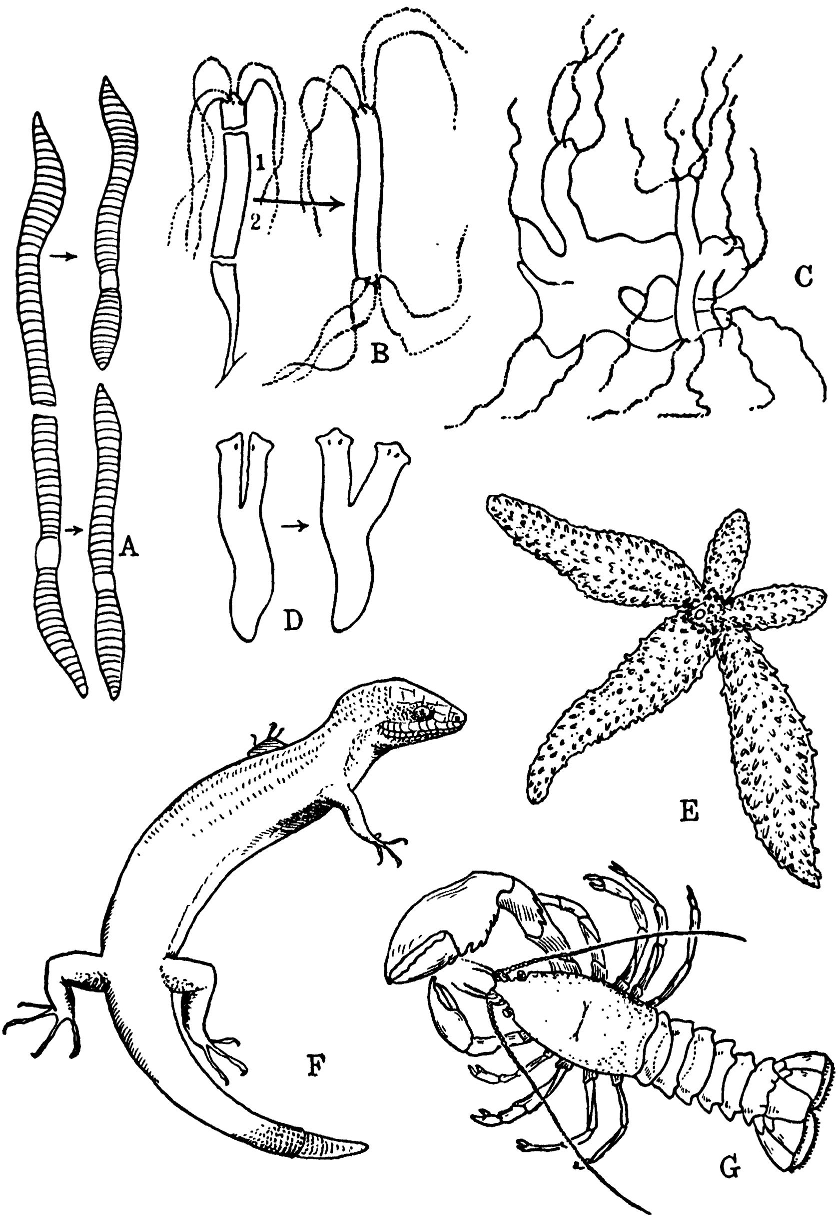


FIG. 151. Regeneration. *A*, regeneration of the earthworm. *B* and *C*, regeneration of *Hydra*. *B*, section 1–2 develops into two-headed animals. *C*, reconstitution of a mass of approximately 125 pieces of *Hydra*. *D*, divided anterior end of a planarian (flatworm), develops two heads. *E*, starfish regenerating two arms. *F*, lizard regenerating new tail. *G*, crayfish developing new claw.

animal withdraws its mutilated organs into the body cavity and replaces the loss by regeneration. If the posterior end of the earthworm is lost, the animal replaces it. Pieces of hydra and planarians will likewise form new animals (Fig. 151). Perhaps the most interesting exhibition of regeneration is put on by sponges. If these animals are squeezed through cloth into sea water, the small unicellular fragments or groups of cells collect in little clumps and grow into new sponges. This power of regeneration is found in varying degrees throughout the animal kingdom. In man, when portions of the liver are lost through operations or otherwise, new liver cells regenerate to replace those lost. Likewise there is some regeneration of nervous tissue and bone.

Some animals possess not only the power of regeneration but also a capacity to lose or to break off appendages at certain places called "breaking joints." This power of automatic surgery is called **autotomy** (*autos*—self; *tome*—cutting). Some crabs throw off their legs or pincers quite readily when handled, and often the captor of a lizard is left with a writhing tail in his hand while the lizard makes its escape. These animals eventually regenerate the parts lost or broken off.

Sexual Reproduction

Sexual reproduction takes place in practically all animals. It is much more prevalent than asexual reproduction, and in most animals it is the only type of reproduction. In some of the lowest forms there may be an **isogamous** condition comparable to that of such plants as *Spirogyra* and *Ulothrix* already described. In a one-celled paramecium, two animals may unite, exchange nuclear material, and then separate (Fig. 152). This process is called **conjugation** (*cum*—together with; *jugare*—to yoke). However, in almost all animals, sexual reproduction involves the union of a small, usually motile, microscopic male gamete or **spermatozoon** (*sperma*—seed; *zoon*—animal) with a larger, non-motile, food-laden gamete, called the **ovum or egg.** The gametes are found in specialized structures called **gonads** (*gone*—that which generates). The male gonads are the **testes,** and the female the **ovaries.**

The sex mechanism. The essential organs involved in sexual reproduction are the ovaries of the female and the testes of the male, together with their ducts by which the gametes can be released from the animal. The ovaries and testes are made up of germinal tissue and supporting tissue. The germinal tissue contains the primordial germ cells which later become mature ova or spermatozoa. Other

structures associated with these organs may be regarded as accessories or special devices to assist in bringing about the union of egg and spermatozoon, to protect the zygote, and to furnish nourishment for the developing embryo.

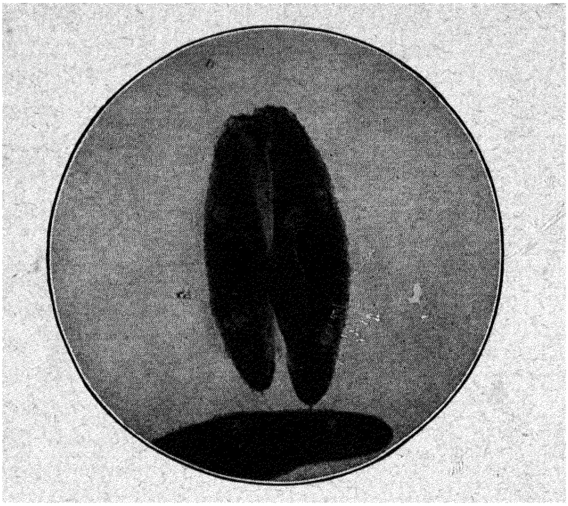


FIG. 152. Conjugating paramecia. *Photomicrograph by the General Biological Supply House.*

The female reproductive system with its accessories is constructed according to the following general plan (Fig. 153). Most of the higher animals have two ovaries, suspended from the body wall into the coelom by mesenteries. Birds have only one functional ovary. Opening near the ovary is a tube, the **oviduct** (*ovum*—egg; *ducere*—to lead), which is rather slender at the ovarian end but which may become enlarged at its lower end to form a region called the **uterus** (*uterus*—womb). The frog and some other animals have two uteri, but in man the oviducts lead to one common, roughly triangular-shaped uterus. In some animals the uteri may open into the cloaca, but in man and related animals there is a new structure, the **vagina,** which leads to the outside. The eggs burst from the ovary and are collected by the oviducts, down which they pass. In some animals accessory material is added to the egg. Thus in the bird the "white" of the egg, the various membranes, and the shell with its pigment are formed around the egg as it comes down the oviduct. In other animals nutritive material is added from **nidamental glands** (*nidus*—nest). In certain animals the eggs are retained in the uterus, where they develop into offspring.

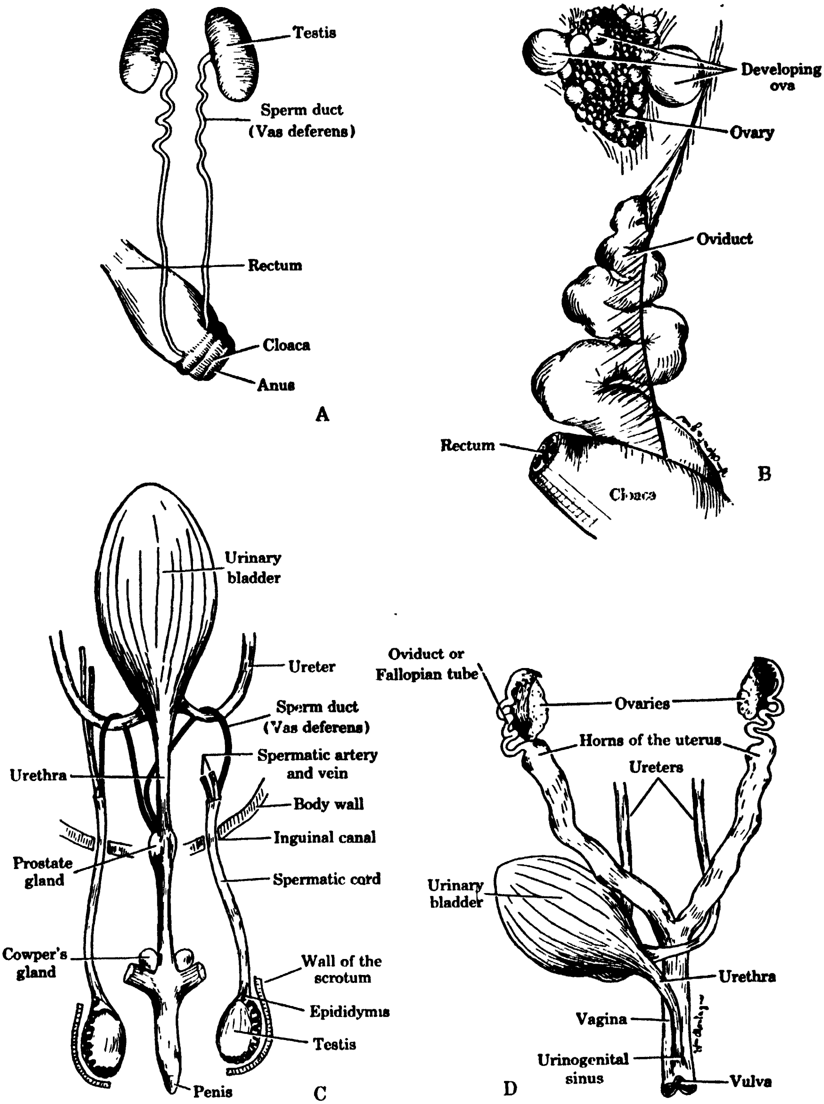


FIG. 153. Genital systems of bird and mammal. *A*, chicken (male); *B*, chicken (female); *C*, cat (male); *D*, cat (female).

The male reproductive systems of most animals have many points of resemblance. As previously pointed out the essential organs are the testes together with their ducts that convey the mature spermatozoa to the outside of the body. Testes vary in shape and number among the lower animals, but in the higher forms there are usually

two testes together with various accessory organs and glands. In the backboned animals the testes are paired, ovoid bodies which may be either suspended in the body cavity or borne outside the body cavity in a sac called the **scrotum** (Figs. 153 and 168).

The testis is made up of germinal tissue, from which the spermatozoa form, connective tissue, and nutritive tissue to provide for the

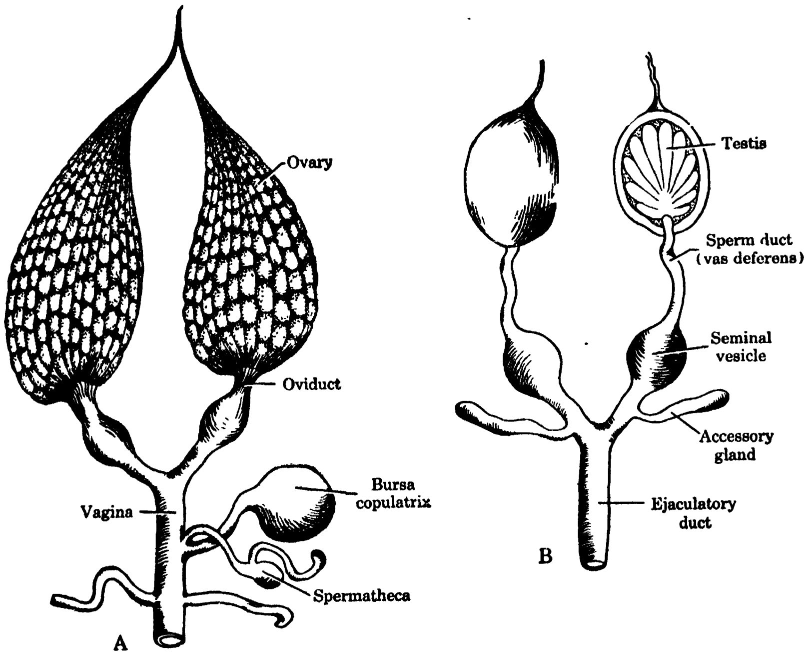


FIG. 154. Genital systems of the male (*A*) and the female (*B*) honeybee. *Redrawn from Comstock, "A Manual for the Study of Insects." By permission of the Comstock Publishing Company.*

developing spermatozoa. Other tissues are present which secrete the hormones of the testis. Small convoluted tubules known as **seminiferous tubules** (*semen*—seed; *ferre*—to carry) convey the spermatozoa into a duct known as the **sperm duct (vas deferens)** which leads from the testis. The sperm ducts often have modified saccular regions for the storage of spermatozoa, called **seminal vesicles.** The sperm ducts in some animals open into the **cloaca** and in others into the **urethra,** a duct which, in the male, carries both spermatozoa and urine to the exterior. In man and closely related animals there may be present **Cowper's gland** and the **prostate gland** whose secretions contribute to the fluid in which the spermatozoa swim. Study

Fig. 154, and compare the reproductive systems of various invertebrate animals with those of the vertebrates.

Hermaphroditism. In most animals only one kind of sex organ is present, ovaries or testes. Such animals are **dioecious.** However, there are other animals which normally have both ovaries and testes present and functional. They are called **hermaphrodites** (*hermaphroditos*—combining both sexes) or **monoecious** animals. Very few vertebrates are true hermaphrodites, but hermaphroditic invertebrates, such as tapeworms and the common earthworm, are numerous (Figs. 219 and 236).

In true hermaphroditic forms functional spermatozoa and eggs are produced by one individual. Sometimes the spermatozoa and eggs of the same animal unite, but most often cross-fertilization is insured by the position of the sex glands and accessories so that it is impossible for self-fertilization to take place. In some hermaphroditic animals eggs and spermatozoa do not mature at the same time. In fact the individual may first be a male and later change to a female, or vice versa. In some animals including the vertebrates many individuals are found which have some of the behavior characteristics and the sex organs of both sexes; as a rule only one set of organs is functional, and quite often the animal is sterile. Such animals are not true hermaphrodites but are usually spoken of as **intersexes** (*inter*—between; sex), although dubbed "morphidites" by the man in the street.

Parthenogenesis. One of the supposed functions of the spermatozoon when it enters the egg is the activation of the egg to cause development. Many people have the notion that an egg will not develop without fertilization. In many insects eggs develop into new individuals like the parent without any assistance of the male. In fact there are some species of invertebrates where only females are to be found for long periods of time. In the bees, as is well known, there are queens and workers which are females, and drones which are males. The queen in her marriage flight receives, from the male, spermatozoa which are stored in her body in seminal receptacles. When she returns to the colony and lays eggs, she lays some eggs which are fertilized; these develop into queens and workers. But some eggs are unfertilized, and they give rise to drones. The development of an egg without fertilization is called **parthenogenesis.** Some animals during the summer produce parthenogenetic eggs, which develop into females. In the fall, males as well as females are produced and the eggs are fertilized. Such zygotes have

hard, fairly thick shells around them, which enable them to resist cold winter temperature.

Parthenogenesis not only will take place under natural conditions but also can be induced artificially. Frog eggs will start development after being pricked with a needle. Eggs of some animals, such as the sea urchin, require only a vigorous shaking to initiate development. Some of the other artificial means of initiating parthenogenesis are application of various acids to the eggs and even changing the eggs from sea water to fresh water.

Breeding activities and fertilization. The behavior and actions of animals during the periods preceding and following the release of the germ cells are usually called **breeding activities.** They vary widely but are concerned with the common purpose of bringing the ova and spermatozoa into close proximity and insuring fertilization. **Fertilization,** in the strict sense of the term, is the actual union of a male gamete with a female gamete to form a zygote.

In animals, the actual release of eggs and spermatozoa may be brought about by change in metabolic conditions which in turn are the result of stimuli. Thus, in some of the aquatic worms, animals of either sex appear to give off substances into the water which stimulate members of the other sex to sexual activity. The change in the physiological activities appears to occur in rhythmic cycles. One of the classic examples of rhythmic activity is offered by the palolo worm (Fig. 155). When the day of the last quarter of the October-November moon dawns in the southern Pacific, fragments of these worms containing the sex organs break off and come to the surface in such numbers that the water "writhes with worms" and later becomes milky with shed eggs and sperms. This wedding day of the worms is the feast day of the South Sea Islander, who holds the palolo worm in high esteem as a delicacy. In one of the sea urchins the eggs and spermatozoa are shed at the period of the full moon of the breeding season. It is common knowledge that frogs and toads take to the ponds and streams in the spring of the year to lay their eggs and that fishes spawn at regular intervals. In many of the mammals, such as cats, dogs, horses, pigs, and cattle, there are cyclic periods of sexual excitement when the female will receive the male. This periodic condition is known as "heat," "rut," or **estrus** (*oistros* —gadfly, frenzy). At these periods the eggs are released from the ovary, a process known as **ovulation.** In the human female, ovulation occurs at regular intervals of approximately every twenty-eight days.

The eggs of the bizarre little fish, the sea horse, are placed in a brood pouch which is found on the male! Perhaps the most interesting adaptation for the care of the young is found in the Surinam toad (Fig. 156). The male places the eggs on the back of the female where "a little lidded pouch arises for each of them." Here the egg

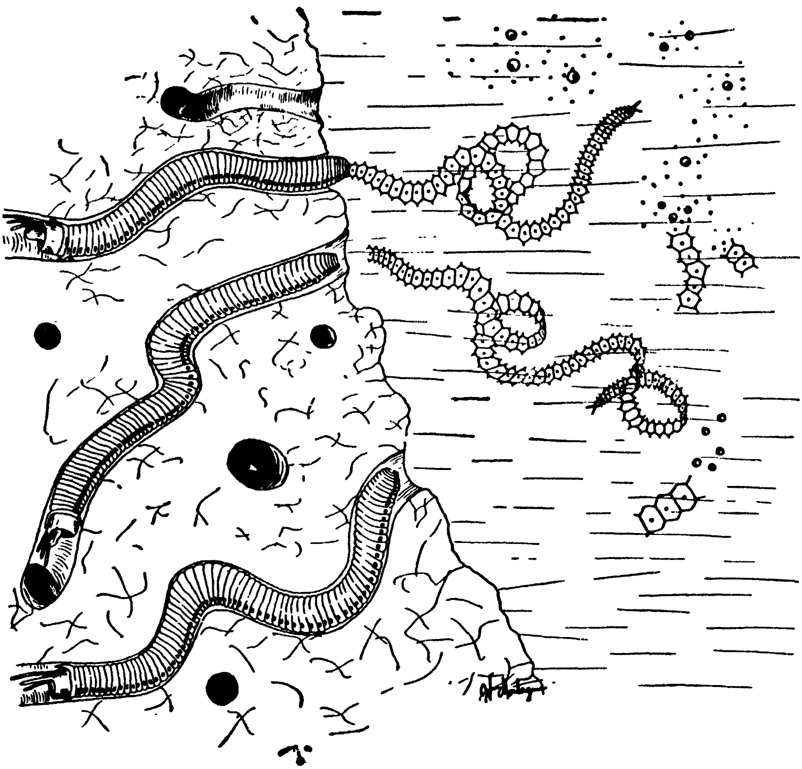


FIG. 155. Swarming of palolo worm. (*After Woodworth, and Borradaile and Potts.*)

develops into the adult form. The care of the young by the kangaroo and opossum is well known. The young are born in a rather immature condition and are transferred to the brood pouch in which the mammary glands (milk glands) open by the teats, to which the young are anchored by their mouths. The young animal which requires the longest period of parental care is man. There are numerous other intensely interesting and almost unbelievable examples of care and lack of care of eggs and young to be found in the animal kingdom. The few examples just cited serve to show some interesting phases of breeding behavior.

It has been pointed out that the egg of most animals is large and non-motile and that the spermatozoon is microscopic and motile. The difference in size is largely cytoplasmic, for the nuclei of both mature eggs and spermatozoa usually contain the same number of chromosomes and the same amount of chromatin. The spermatozoon

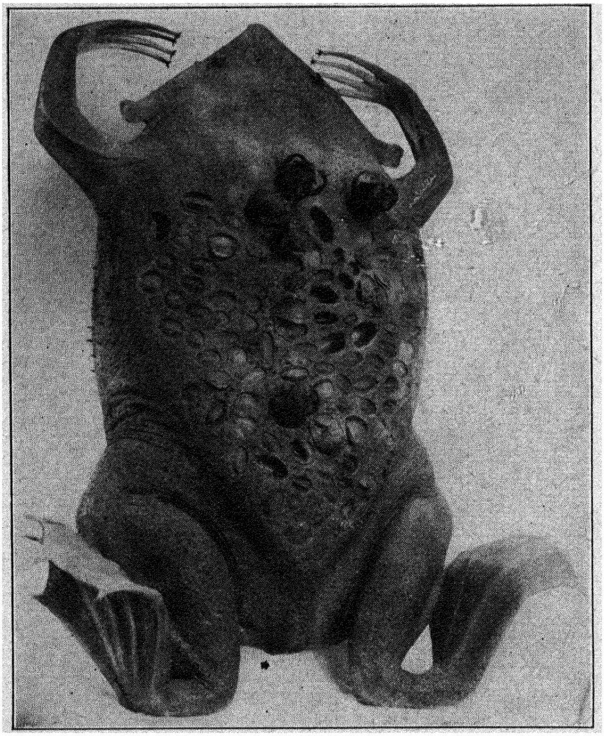


FIG. 156. Surinam toad. Note the small toads developing in pouches on the back of the female. *Photograph furnished by the American Museum of Natural History, New York.*

is commonly equipped with a tail whose lashing propels it forward. The motility of the spermatozoa and the fact that they are produced in so much greater numbers than the non-motile eggs increase the chances for fertilization. Another factor which assists in bringing about fertilization in some aquatic animals is a substance given off by the eggs called **fertilizin** which attracts and aggregates spermatozoa. In addition to the factors just mentioned for insuring fertilization, some animals lay or produce enormous numbers of eggs. The female oyster, for example, lays between 16,000,000 and 60,000,000 eggs, and a sea urchin releases about 10,000,000 eggs.

It is estimated that if all the eggs of the oyster were to be fertilized and developed and this progeny multiplied, the great-great-grandchildren would number 66,000,000,000,000,000,000,000,000,000,000,000 (Fig. 157). The shells of a generation would make a mountain eight times the size of the earth. This prodigality of production seems necessary, for, since the eggs are thrown out into the sea, fertilization is a matter of chance. Moreover, many of the eggs are eaten by other animals, and even during development millions of them perish as the

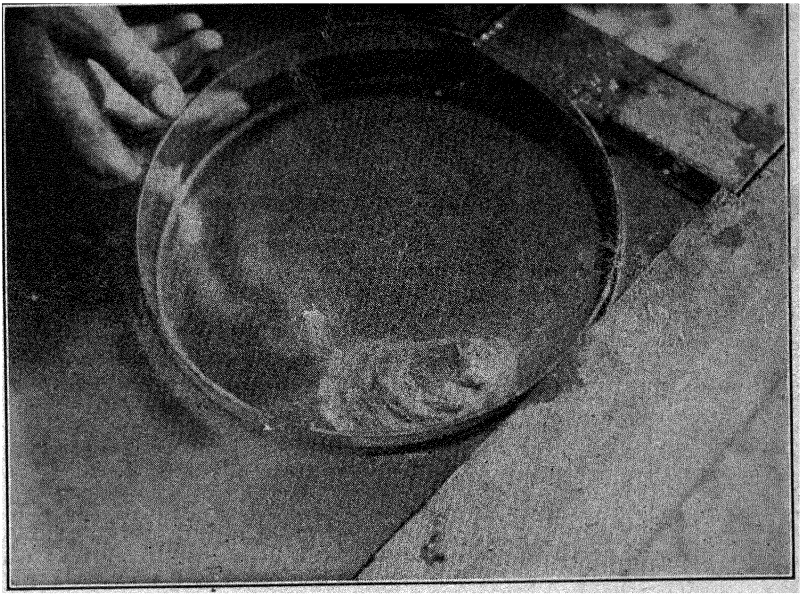


FIG. 157. Oyster laying eggs. The eggs appear as a cloudy mass extending from the edge of the shell. *Photograph furnished by Fish and Wildlife Service, U. S. Department of the Interior (Paul S. Galtsoff).*

result of hungry enemies and adverse environmental conditions. The following from Tennyson seems quite applicable to the situation:

So careful of the type—
So careless of the single life.

In toads, frogs, and other animals, the male attaches himself to the female, and, as the eggs pass from the body, the milt or spermatic fluid is poured over them, thus to a large extent insuring fertilization. In the higher animals the spermatozoa are deposited by the male in the cloaca or the vagina of the female, and the eggs are fertilized while in the body of the female. In some animals the eggs are laid later and develop outside the body; in others the eggs develop inside the body.

Care of the eggs and young. Animals like the birds, frogs, and many reptiles whose young develop from eggs outside the body are

called **oviparous** (*ovum*—egg; *parere*—to bring forth); and those animals like cats, dogs, and man whose young develop from eggs retained in the body are said to be **viviparous** (*vivus*—alive; *parere*). There is little variation in the method of caring for the eggs in viviparous animals since the eggs are retained in the uterus where they develop into young animals. However, among the oviparous

FIG. 158. Parental care. Note the male hornbill feeding the female shut in by a wall of mud while incubating the eggs. *Photograph furnished by the Victor Animatograph Corporation.*

animals there is a wide variation in the method and detail of egg disposal and of the care of the young. Certain animals lay their eggs and leave them virtually unprotected. The young have to shift for themselves. The cowbird is extremely callous maternally. She lays an egg in the nest of some other bird, such as a chipping sparrow or a warbler. The egg is larger than those of the owner of the nest, and, when it hatches, the young cowbird is larger than the rightful heirs. It gets more than its share of food, and sometimes even pushes the rightful heirs out of the nest. Perhaps the other extreme among birds as far as parental care is concerned is exemplified by the rhinoceros hornbill (Fig. 158). The eggs are laid in a hollow tree and incubated by the female. The male walls her in with a layer of mud, in which there is an opening large enough for her bill

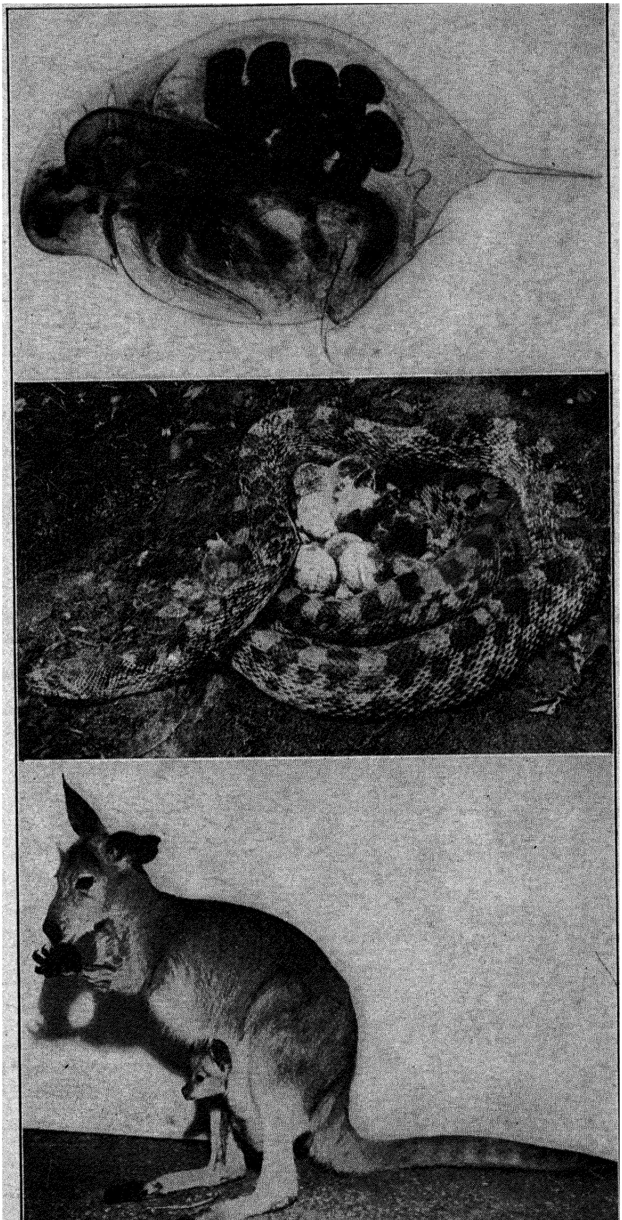


Fig. 159. *Above, Daphnia* with young in brood pouch. *Middle,* pine snake with eggs. *Below,* kangaroo with young in pouch. *Photograph above furnished by Albert E. Galigher; middle, by National Zoological Society; below, New York Zoological Society.*

to be extruded. The male bird stands by, gets food, and feeds the female during the period of incubation.

The alligator makes a nest of decaying vegetation and depends upon the heat of decay to incubate the eggs. Both alligator eggs and snake eggs can be incubated in boxes of sawdust or other suitable material. Some snakes and lizards remain with the eggs. For instance, the python coils around its eggs and assists in incubation. In some animals the eggs are not even put in a guarded nest but carried around by the parent. The female crayfish attaches the eggs to the appendages under the abdomen and here even the young crayfish may be found clinging after hatching.

Some of the wasps make a nest or tube of mud in which the eggs are laid. The wasp provisions the nest by stinging and paralyzing a caterpillar so that when the egg hatches there will be plenty of food for the young.

Development of the Individual—Embryology

We have now described the origin and development of the young plant and have studied the initial stages in the origin of the individual animal. Mature gametes, i.e., eggs and spermatozoa, were produced, and the union of the two germ cells was brought about to form a zygote, often erroneously called a "fertilized egg." We will now observe the development of the individual from the zygote.

Cleavage. The zygote, although the result of the union of two sex cells, is nevertheless a single cell. This single cell by mitosis now divides into two cells called **blastomeres** (*blastos*—bud; *mere*—part). These divide into four blastomeres, the four into eight, and so on until eventually by this process of cell multiplication, or **cleavage,** there is formed a single-layered hollow ball of cells known as a **blastula** (*blastos*—bud; *ula*—little). The space or cavity inside the blastula is called the **blastocoel** (*blastos; koilos*—hollow) (Fig. 160). If the yolk is fairly evenly distributed the entire zygote will divide and the cells will be approximately equal in size. This is called **holoblastic cleavage** (*holos*—whole; *blastos*). The human zygote undergoes holoblastic cleavage.

Some eggs, like those of the bird, have an abundance of yolk unequally distributed to one pole of the egg. Here cleavage is restricted to one region or pole of the egg, and a little disk of cells is formed which is often seen on the yolk of the chicken egg. This type of cleavage is known as **meroblastic** (*meros*—part; *blastos*). The pole of the egg where the cells are smaller and more numerous is known as the **animal pole,** and the region where the bulk of the yolk is located is called the **vegetal pole.**

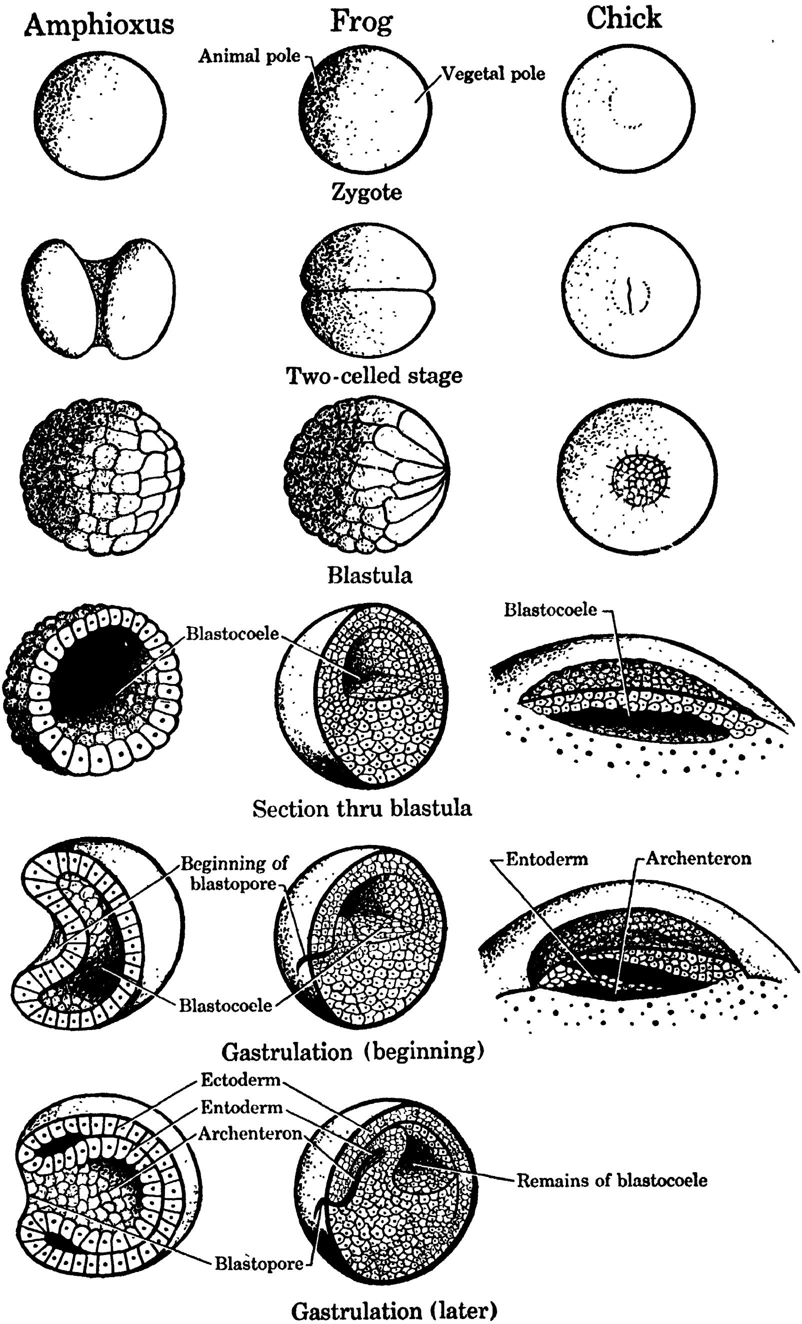


FIG. 160. Cleavage of the zygotes of *Amphioxus*, frog, and chick.

As the cells continue to multiply, the blastula undergoes a transformation whereby the blastocoel is practically obliterated and there is formed a two-layered saclike structure enclosing a new cavity. This developing organism or embryo is known as a **gastrula** (little stomach). The outer cell layer is the **ectoderm** (*ektos*—outside; *derma*—skin); the inner the **endoderm** (*endon*—within; *derma*). The sac formed by the endoderm is the **archenteron** (*arche*—beginning; *enteron*—gut) which opens to the outside through the **blastopore** (*blastos; poros*—passage). Soon a third layer of cells forms between the ectoderm and endoderm called the **mesoderm** (*mesos*—middle; *derma*) (Fig. 160). These three layers are not found in animals like sponges and hydras.

When yolk is evenly distributed through the egg, as in the **isolecithal eggs** (*isos*—equal; *lecithos*—yolk), the blastomeres are relatively equal in size; but in **telolecithal eggs** (*telos*—end; *lecithos*), such as the frog's, the yolk is more abundant at the vegetal pole and cleavage progresses more slowly in that region. The result is unequal cleavage in both cell number and cell size. The cells formed at the animal pole are smaller and much more numerous. Gastrulation is brought about by an overgrowth of the ectoderm over the endoderm. Where cleavage is confined to a disklike region on the yolk, as in the bird and reptile egg, it is known as **discoidal cleavage,** a form of meroblastic cleavage. Insect eggs are known as **centrolecithal eggs,** for the yolk is collected in the center. The nucleus in the center of the yolk mass divides, and the daughter nuclei migrate to the surface of the egg. Cell walls form around them, and eventually the central mass is surrounded by cells. This type of cleavage is called **superficial.** The flatworms, annelids, and most mollusks exhibit what is known as **spiral cleavage.**

The ectoderm, the endoderm, and the mesoderm are the **primary germ layers,** and from them come all the tissues and organs of an adult animal. The ectoderm gives rise to nervous and sensory structures such as the brain, spinal cord, nerves, retina, ear, and taste buds. The epidermis and such structures as hair, nails, some fish scales (in part) and reptile scales, and the enamel of the teeth are also derived from ectoderm. The mesoderm gives rise to the supporting tissues of the body (muscle, bone, and connective tissue), the heart, blood, and kidneys. From endoderm is derived the epithelium of the pharynx, thymus, thyroid, respiratory tract including lungs, trachea, digestive tract, and associated glands. This general outline will provide a basis for the study of the further development of the embryo.

Formation of the embryo. The gastrula elongates as a result of the rapid multiplication of the cells of its primary germ layers, especially those of the ectoderm and endoderm. As the embryo elon-

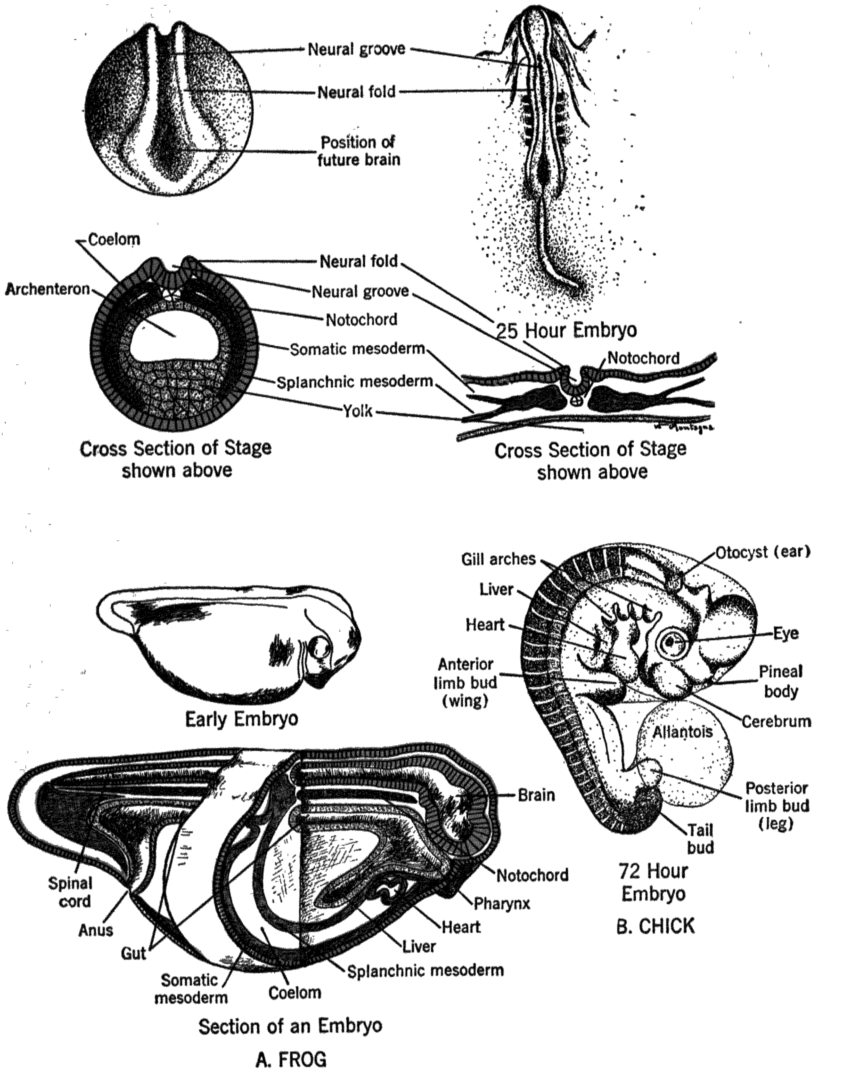


FIG. 161. Early development of frog (*A*) and of chick (*B*). Endoderm shown in yellow, ectoderm in blue, and mesoderm in red.

gates, the ectoderm of the dorsal region thickens along the midline to form the **neural plate,** which sinks slightly below the surface of the embryo. Owing to unequal growth, the sides of the neural plate push up above the general surface of the embryo, forming the **neural folds,** between which is a long depression called the **neural groove** (Fig. 161). The two folds diverge at the anterior end of the groove. The parallel neural folds rise higher and higher, grow together, and eventually fuse to form an ectodermal tube, the **neural tube,** which is now completely sunk below the general surface of the embryo and covered by the surface ectoderm. The narrow region of the neural tube eventually becomes the spinal cord, and the broader, expanded region forms the brain.

Simultaneously with the formation of the neural plate and its differentiation into the spinal cord and brain, other changes are taking place. Under the neural plate a long axial rod of cells called the **notochord** has formed. The mesoderm has developed between the ectoderm and the endoderm. The mesoderm first appeared as two sheets of tissue extending laterally from the region of the notochord and neural tube toward the ventral region. Eventually the mesodermal sheets split into an inner layer of **splanchnic** mesoderm, which is closely applied to the endoderm of the enteron to form the **splanchnopleure** (*splanchnon*—gut; *pleura*—side), and an outer layer of somatic mesoderm applied to the ectoderm to form the **somatopleure** (*soma*—body; *pleura*). The space between these two layers is the **coelom** or **body cavity** (Fig. 161).

It should be noted that many organs or body structures are derived from more than one primary germ layer. Thus in the intestine the digestive epithelium or mucosa with its goblet cells is derived from endoderm, but the connective tissue, muscles, blood vessels, and peritoneal layer are derivatives of the splanchnic mesoderm. In the eye the retina and lens are ectodermal structures, but the sclera, choroid coats, and muscles which move the eye are derived from mesoderm. The study of the development of tissues in the formation of the body structures is one of the most interesting phases of biology.

The building of organs. The archenteron which originally was in communication with the outside world by the blastopore soon becomes a closed sac or tube. The mouth and anus form later when inpushings of the ectoderm to the endoderm make pouches which later break through the archenteron. In the early stages of embryonic vertebrates there push out from the walls of the pharynx paired pockets called **pharyngeal pouches** (Fig. 161). In fishes and some

amphibians these may break through to the exterior. In most of the higher vertebrates under normal conditions they do not break through. In man, the first pharyngeal pouch remains as the Eustachian tube. The closed end of this pouch, which in fishes breaks through to the outside, becomes the tympanum or eardrum. In the fishes, **gills** develop on the walls or **gill arches** which separate the gill slits. The troublesome tonsils, the parathyroids, and the thymus are other remnants of the gill pouches of a fish ancestry (Fig. 161).

The liver is an outpushing from the primitive enteron. Just back of the liver is another outpushing which forms the pancreas. The connective tissue for these organs is furnished by the surrounding splanchnic mesoderm. Farther toward the mouth the lungs arise as an outpushing from the floor of the pharynx. As the animal grows, this tubular structure elongates and divides at the posterior end into two equal branches which differentiate into the bronchi and lungs, and the tube itself becomes the trachea. The end of the trachea, near its opening into the pharynx, appropriates some remnants of the now useless gill arches for supporting cartilages and forms the larynx. The region of the primitive gut just anterior to the liver differentiates into the stomach. The more posterior regions develop into the much-coiled small intestine, large intestine, and urinary bladder.

The ear arises as a thickened patch of ectoderm along the side of the head. This thickened area pushes in to form a pear-shaped sac which undergoes a series of changes that convert it into the ear. The auditory nerve grows out from the brain to supply the ear. The bones of the ear are derived from mesoderm and are remnants of former gill arches which in the earlier ancestors may have supported gills. The Eustachian tube is a made-over pharyngeal pouch or gill pocket. The lining of the nostrils arises in somewhat the same manner as the ear, from pockets of thickened ectoderm.

It has already been pointed out that the spinal cord and brain are formed from the neural folds and neural plate. The formation of the eye is an interesting phenomenon. A hollow outgrowth called an **optic vesicle** pushes out from the brain and becomes invaginated at its free end to form a sort of double-walled cup called the **optic cup,** the inner layer of which is the retina. The connection of the optic vesicle with the brain is known as the **optic stalk** (Fig. 163). When the optic vesicle touches the outer ectoderm, the region it touches thickens and pushes below the surface to form a hollow vesicle that becomes the **crystalline lens.** Apparently the optic vesicle acts as a stimulus on the ectoderm, resulting in lens formation, for, if a piece

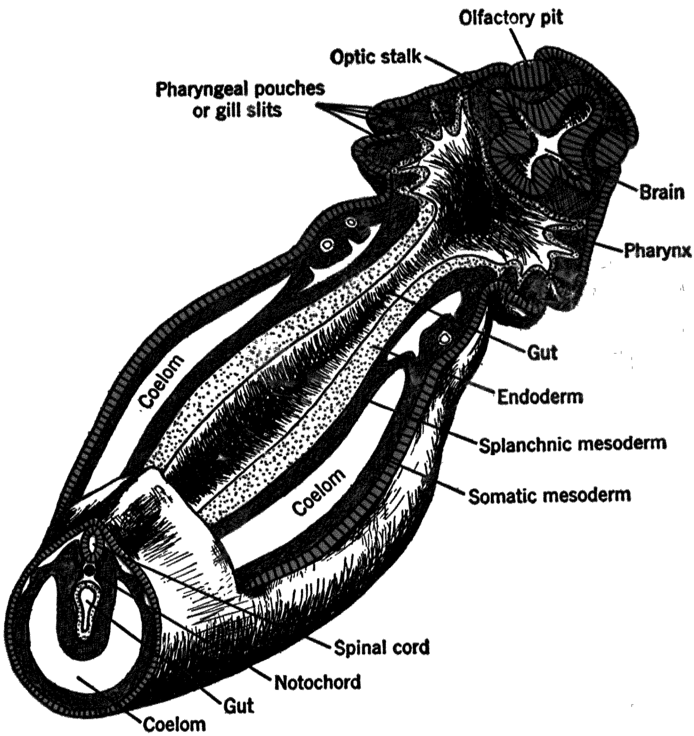


FIG. 162. Diagram of the frog embryo with a part of the dorsal half of the body removed.

of the optic vesicle of certain amphibians is transplanted beneath the ectoderm in some other part of the embryo, a lens will form. If, however, the optic vesicle is prevented from touching the ectoderm, no lens is formed. The narrowed region of the stalk, which connects the optic cup to the brain, becomes the optic nerve. We have already pointed out in a general way the origin of other structures of the eye.

From the foregoing we see that in general the development of the embryo is brought about by thickening and thinning of various re-

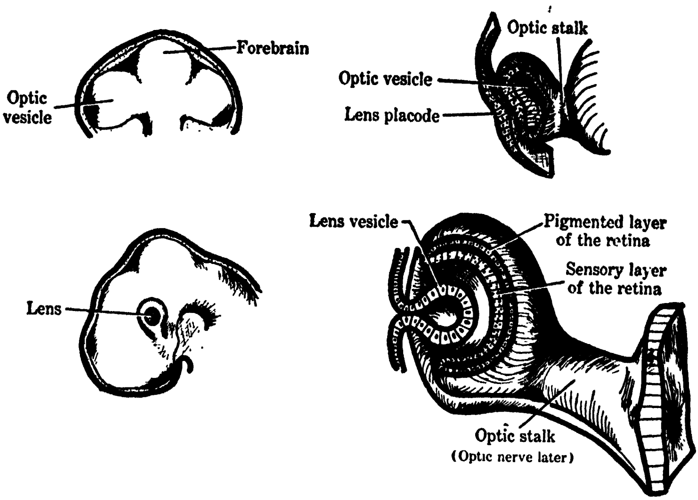


FIG. 163. Development of the eye, an ectodermal structure. *Redrawn from Arey, "Developmental Anatomy." By permission of the publisher, W. B. Saunders Co.*

gions of the embryo; by inpushings and outpushings; by splitting and fusions; by cell multiplication; and, finally, by specialization of generalized cells from the primary germ layers.

What has just been said about the development of vertebrates is also true in general of the development of invertebrates. However, certain variations occur in mode of cleavage and gastrulation. In the invertebrates there are some interesting modifications of mesoderm and coelom formation. Thus sponges and coelenterates (jellyfish, hydras, corals, and others) are not much more than gastrulas when fully developed.

In the starfish the mesoderm is derived from two pouches that push out and pinch off from the enteron. These hollow pouches grow down between the endoderm and ectoderm, coalesce ventrally, and their cavity becomes the coelom. Again, in the earthworm we find that the mesoderm is derived from

two primitive cells which originate from one of the large cells formed during cleavage. Other interesting invertebrate developmental processes might be described as well as various interesting and bizarre larval forms which later transform into adults (Fig. 164).

Homology and analogy. Just as the preceding general description of early development holds true for the vertebrates, so are the later phases of differentiation likewise quite similar. If we study the foreleg and foot, the arm and hand, and the wing of a bird in the earliest embryonic stages, they are all seen to be budlike outgrowths on the

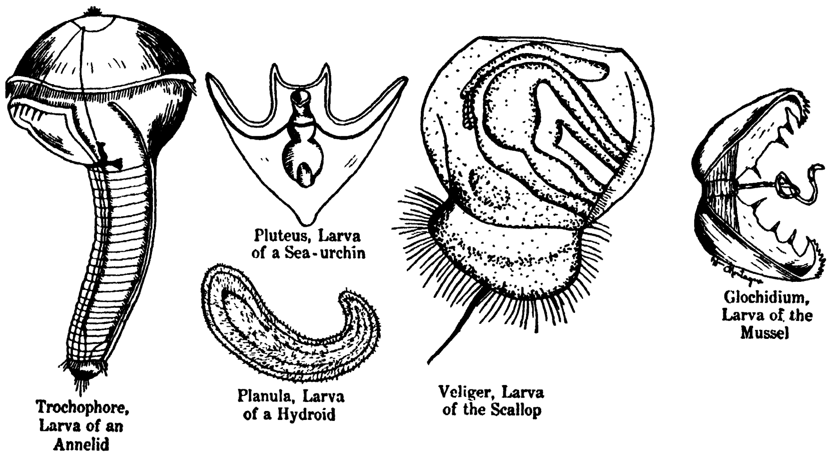


FIG. 164. Various types of invertebrate larvas.

side of the embryo. In fact they are called **limb buds.** As the embryo develops and metamorphoses into the adult, the limb buds change into the structures already mentioned. However, a study of the bones and muscles shows a structural likeness as well as a similar embryonic origin. Such structures, irrespective of function, are said to be **homologous** (Fig. 165). The wings of a butterfly, bee, or other flying insect do not have the same origin and structural similarities as those of a bird or a bat, yet the function, flying, is the same for all these animals. Structures, then, which have the same function but whose origin is different are said to be **analogous.** Different types of homologous structures may be found in various organs of both the vertebrates and invertebrates, as will be brought out later.

Nourishing and protecting the young embryo. It has already been pointed out that in some eggs there is a much greater amount of yolk than in others and that cleavage is confined to a protoplasmic disk at the animal pole. Here the embryo develops. As the embryo

develops, the splanchnopleure, i.e., the endodermal cells with the accompanying splanchnic mesoderm, grows down over and completely envelops the mass of yolk in a **yolk sac** (Figs. 166 and 167). The yolk thus comes to lie, in a sense, in the primitive alimentary tract.

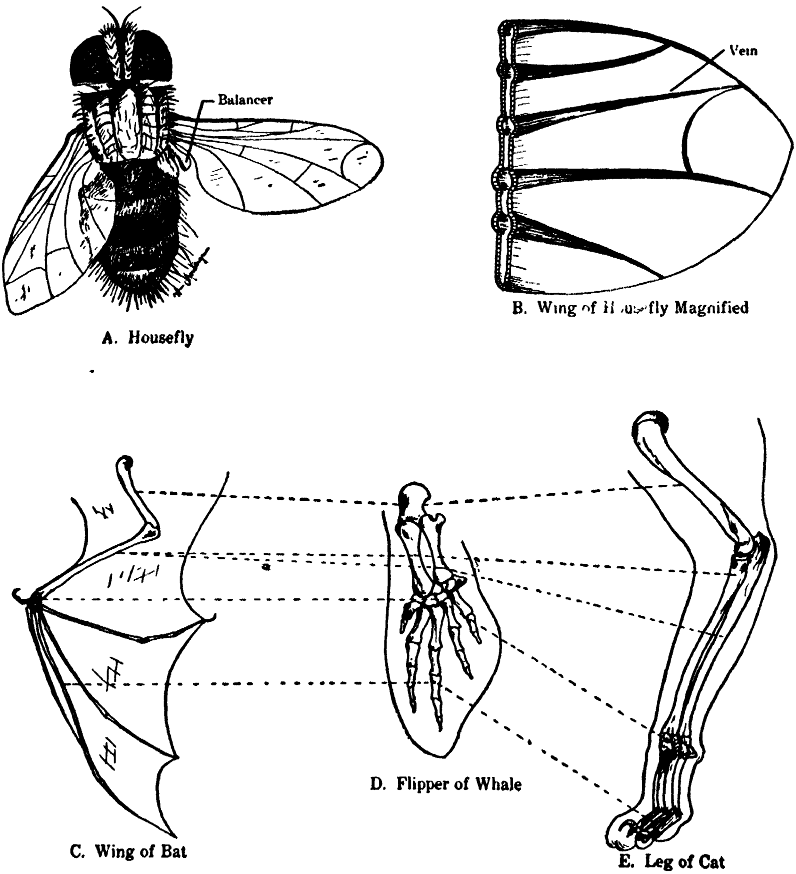


FIG. 165. Homology and analogy. *C, D, E* are homologous; *C* is analogous to *B*.

The embryo continues to grow and becomes almost separated from the yolk, which is being slowly absorbed by blood vessels that have developed in the walls of the yolk sac. However, the embryo still remains attached to the yolk by a narrow **yolk stalk** which communicates with the intestine in the **umbilical region** (*umbilicus*—navel). As the animal grows, the yolk is absorbed, the yolk sac shrinks, and its layers are used to close the intestine.

In fishes and amphibians, the eggs are laid in the water where there

is not only plenty of buoyancy for shock absorption but also ample provision for oxygen supply and waste elimination. And these embryos require plenty of oxygen, because young organisms and young tissues have been shown to have a higher metabolic rate than old ones. They "live" faster. Since reptiles, birds, and mammals do not lay their eggs in the water, provision has to be made to replace this medium functionally. This is done by the development of **embryonic membranes,** which are used for protection, nutrition, respiration, and

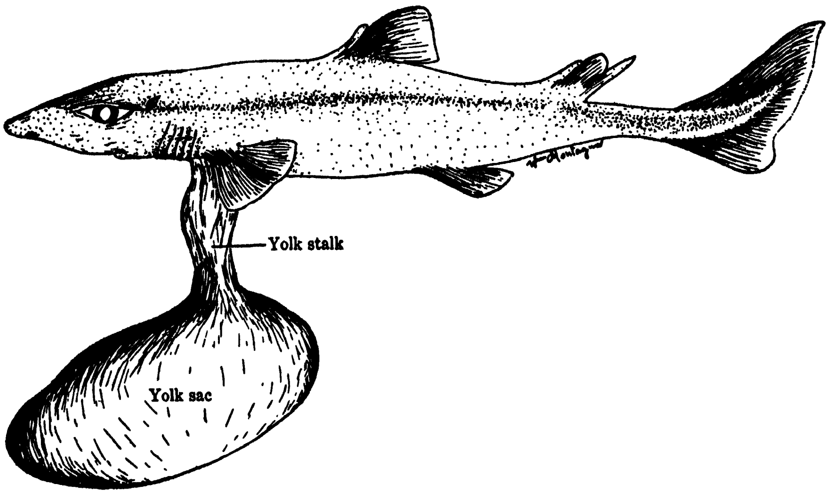
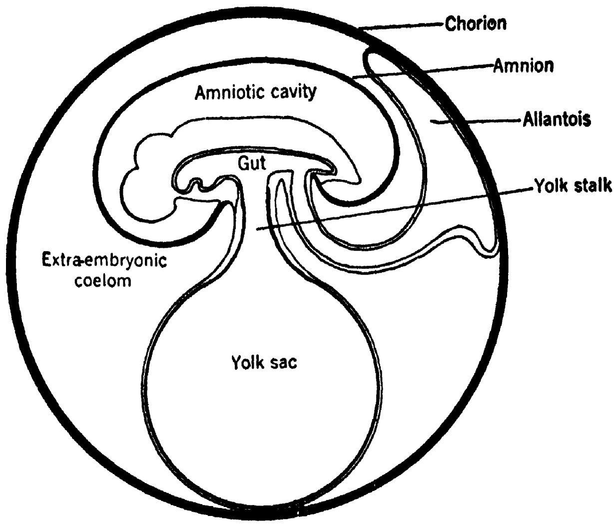


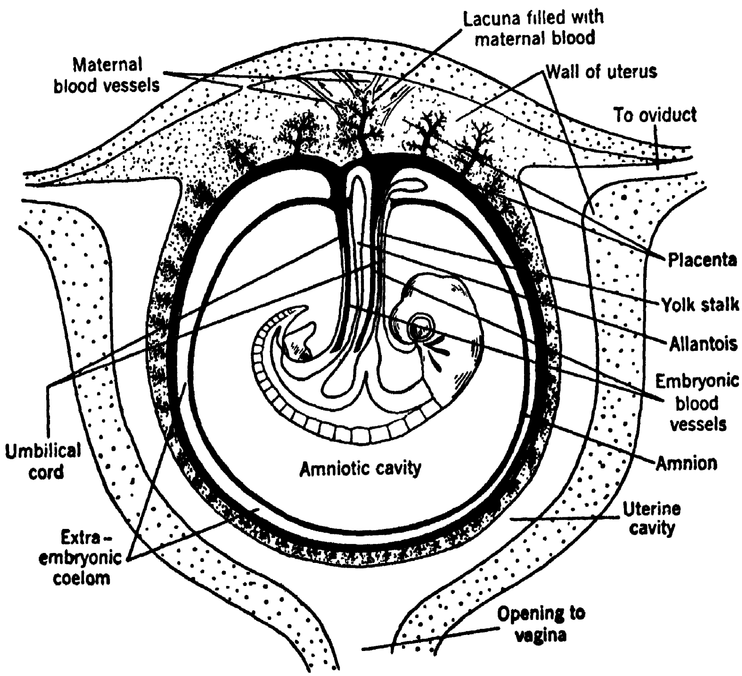
FIG. 166. Embryonic shark.

excretion. In all these animals there are formed a yolk sac and stalk, which function in somewhat the same way as those of fishes and amphibia. However, the egg of some mammals, such as man, has little yolk, and the yolk apparatus is very rudimentary.

In reptiles and birds, folds of the somatopleure grow up over the sides, head, and tail of the embryo, meet, fuse, and enclose the embryo in a sac called the **amnion.** The outer layer of the fold forms the **chorion** (*chorion*—a skin). (Study carefully Fig. 167.) The amniotic cavity is filled with the watery amniotic fluid—the substitute for the pond or the brook of the embryonic fish and frog. To take care of respiration and waste, a pouch called the **allantois** (*allas*—sausage) pushes out from the floor of the gut just back of the yolk stalk. The allantois pushes on out between the chorion and the amnion. Thus it is close to the outer wall of the shell and, being well supplied with blood vessels, solves the oxygen and carbon dioxide



Bird (Chick)



Mammal (Man)

FIG. 167. Embryonic membranes of bird (chick) and mammal (man).

problems of the embryo. At birth these embryonic membranes remain with the shell.

In the majority of mammals, nourishment and waste elimination of the embryo present a somewhat different problem, solved in a somewhat different way. In the first place the mammalian egg is usually microscopic in size and contains little yolk. The tiny egg is fertilized in the oviduct. The zygote passes down and imbeds itself in the uterine wall. Here the developing embryo or fetus forms a yolk stalk, amnion, allantois, and chorion. However, the outer vascular wall of the allantois is fused with the chorion. Eventually, the amnion increases in size until its walls are in contact with the chorion. In man and many mammals, branching fingerlike processes called **chorionic villi** push out from the chorion at one restricted disklike region. The villi erode close-fitting pits in the wall of the uterus. This uterine-chorionic organ is known as the **placenta.** The embryo is attached to the placenta by a rather long, twisted cord of tissues called the **umbilicus,** in which are found the rudimentary remnants of the yolk stalk and allantois, as well as two arteries and a vein which carry the fetal blood to and from the placenta (Fig. 167).

Reproduction in man. We have already discussed the reproductive activities of animals in general. We shall now study this process more specifically as it occurs in man. The human reproductive systems are quite similar in many respects to those of other animals, particularly other mammals. In the male, the spermatozoa are formed in the two testes which are located outside the body in a sac known as the **scrotum.** The spermatozoa are formed in the minute, much-twisted tubules of the testes and finally leave the testes by the sperm ducts, two tubes which enter the abdominal cavity through the **inguinal canals** and lead to the urethra, into which they open (Fig. 168). Just before a sperm duct enters the urethra there opens into it a small pouch or sac known as a **seminal vesicle.** It is known that the seminal vesicles secrete a fluid, but it is doubtful that spermatozoa are stored here as was formerly thought. Where the sperm ducts enter the urethra there is a gland about the size and shape of a chestnut, the **prostate gland.** The secretions of the prostate gland and seminal vesicles, in which the spermatozoa swim, make up the bulk of the **semen** (*semen*—seed). The semen is discharged through the urethra, which courses through the very vascular, spongy, intromittent organ, the **penis.**

The female reproductive system consists of the two ovaries in which ova as well as hormones are formed. The ovaries are almond-

shaped organs suspended in the body cavity by mesenteries. Near each ovary is the expanded funnellike opening of the **oviduct (Fallopian tube)** which extends to one of the two upper corners of the somewhat pear-shaped, very muscular **uterus** or **womb** (Fig. 169). The tapering end **(cervix)** of the "pear" extends a short distance into the tubular **vagina,** which opens to the exterior (Fig. 169). Thus

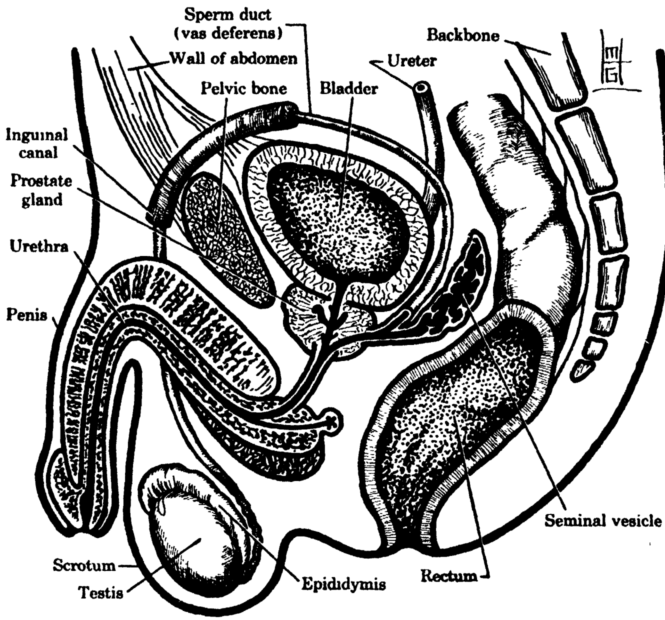


FIG. 168. Diagram of male reproductive system of man. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

there is a continuous passage from the vagina through the uterus, up through the oviduct to the ovaries. Near the entrance to the vagina are glands homologous to the prostate gland in man. There is also a structure homologous to the penis and called the **clitoris.**

We have already called attention to the rhythmic or cyclic reproductive activities of other animals and pointed out that, about the time of ovulation, that is, discharge of the egg from the ovary, there occurs a condition known as estrus. In the human female there is a somewhat similar rhythm of ovulation accompanied by certain changes in the mucosa or lining of the uterus. This series of changes is usually known as the **menstrual cycle** (*mensis*—month).

Usually one egg is released from either one or the other ovary every twenty-eight days. During the years of sexual activity some four

hundred eggs are released. The egg develops in a liquid-filled vesicle, the **Graafian follicle.** As the follicle grows, it forms a bulge on the ovary and finally bursts, freeing the egg. Under normal conditions the egg enters the oviduct. Here it may be fertilized. The cleaving and developing zygote passes down the oviduct and after about three days reaches the uterus. The former Graafian follicle is now succeeded by a growth of endocrine tissue called the **corpus luteum.**

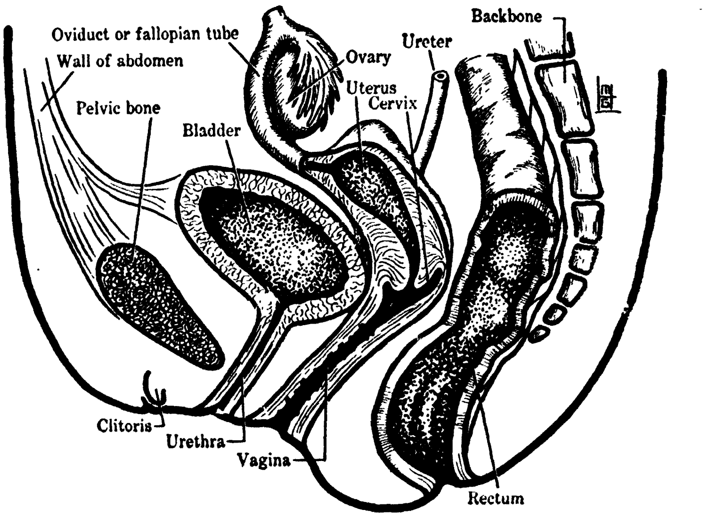


FIG. 169. Diagram of female reproductive system in man. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

We have already discussed briefly the relation between the hormones of the ovary and the pituitary body and their effect on the uterus. On the average, fourteen days before ovulation takes place in the non-pregnant female, the mucosal lining of the uterus sloughs off. Not only do the mucosal cells degenerate, but there may be slight hemorrhage of the smaller uterine blood vessels as well. This process of sloughing off is known as **menstruation,** which may take place over a period of four to six days. The uterine mucosa now undergoes replacement and repair, apparently under the influence of the hormone estrin or theelin from the ovary, the production of which, in turn, is under the influence of the pituitary hormone, **F. S. H. (follicle-stimulating hormone)** (Fig. 170). The uterine lining becomes thicker and softer, better supplied with blood and glands. This is the optimum condition for the reception of a developing zygote and is reached about the time of ovulation or about the four-

teenth or fifteenth day after the onset of menstruation. The hormone of the corpus luteum, progestin, as well as estrin, both dependent upon another pituitary hormone **L. H. (luteinizing hormone),** now apparently regulate the formation of uterine mucosa. Study carefully Fig. 170. If the egg is not fertilized, the uterine mucosa sloughs off usually at the end of twenty-eight days from the onset of the last menstruation, and the menstrual cycle begins again.

If the egg has been fertilized, the developing zygote comes in contact with the uterine wall and imbeds itself. The more basal region of contact develops small, branched projections called chorionic villi which imbed themselves in the uterine wall, the two regions making up the organ of nutrition called the **placenta.** The chorionic villi erode away the maternal tissue of the mother until they are bathed by maternal blood, but there is no mixing of the blood of the mother and the fetus. Each has a separate circulation. The blood of the fetus circulates through the chorionic villi, which project into spaces in the uterine wall filled with maternal blood. Here dissolved food is absorbed, and gaseous and liquid wastes are thrown off. Consequently, any exchange which takes place between mother and fetus is between the respective blood streams which are separated by cellular membranes. As the embryo grows, it completely fills the cavity of the uterus, and normally after ten lunar months of development a child is born.

In birth, the muscular walls of the uterus contract and the amnion bursts releasing the amniotic fluid. The fetus is expelled, and after breathing and circulation are well established the umbilical cord is severed. The embryonic membranes and the placenta are likewise expelled, making up what is known as the "afterbirth."

Some factors modifying development. In the preceding paragraphs, we have tried to outline how the animal organism originates and develops under relatively stable conditions in a uniform environment. Through experimentation, biologists have brought about interesting structural modifications and discovered certain factors governing development. Some of these discoveries are almost unbelievable. For instance, it has been found that, if the blastomeres of *Amphioxus* are separated at the two-cell stage, they will develop into two perfect little animals—twins. Sometimes twin frogs may arise in a similar manner. In some jellyfishes each blastomere in the sixteen-cell stage of cleavage will develop into a perfect embryo. On the other hand, separation of blastomeres, or even groups of blastomeres, of other animals in the early stages of development results in the formation of only those particular structures or regions of the

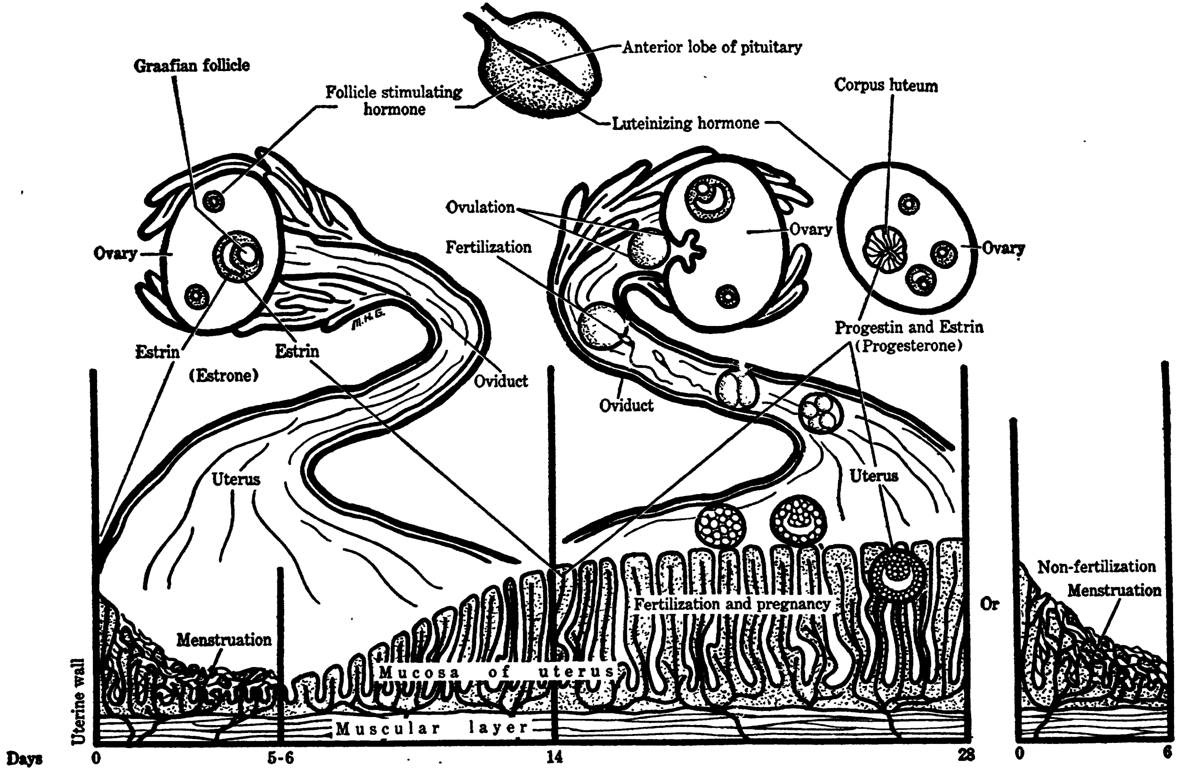


FIG. 170. Diagram showing the sequence of the menstrual cycle and the most important endocrine secretions concerned. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

animal which would have been produced if the cells had remained grouped together. Motile structures of the embryos of some animals will develop and move around without any other parts of the embryo attached, apparently indicating that very early in development each blastomere becomes restricted as to the variety of structures it can produce. Cleavage of this type is called **mosaic cleavage.** Not only are the potentialities of the blastomeres of some animals fixed early in development but also the tissues which develop from the primary germ layers are determined. Thus bits of mesoderm differentiated for muscles, or ectoderm differentiated for nerves, may be removed from the embryo and grown in artificial cultures outside the body, where they will develop into muscle and nerve.

Spemann and other biologists have found that double-headed monsters can be formed from the gastrula of a newt (a tailed amphibian) by tying a hair around the middle of the gastrula in such a way as to divide the dorsal lip of the blastopore (Fig. 171). In another experiment, a gastrula was divided into halves by cutting through the middle of the dorsal lip of the blastopore. One half of the mass was rotated 180 degrees, with the result that there developed two half-embryos facing in opposite directions. By transplanting a portion of the dorsal lip of the blastopore into the side of a young embryo, there was formed a head region indicative of the new axis of an embryo at right angles to the embryo receiving the transplant. Spemann accounts for such unusual developments as the result of an "organizer" which is located in the dorsal lip of the blastopore.

By adding magnesium salts to the water at a particular stage in the development of certain young fish, Stockard has been able to grow fish having a single median eye. Other abnormal fish have been produced by lowering their metabolic rate at certain stages of their development by such methods as reducing the oxygen content of the water and by means of various narcotics (Fig. 171).

Other methods have been found to control the pattern of various animals. *Tubularia* is a simple marine animal which resembles *Hydra*. Its apical region is an enlargement of the stem containing a mouth surrounded by "lips" or peristome, around which are tentacles. These structures make up the hydranth. If the hydranth is removed, the animal will regenerate a new one. If, however, you remove both the hydranth and "foot" (basal) region and then stick the apical region in the sand, a new hydranth forms where the foot formerly was. The former apical region develops into a foot. If neither cut end is put in the sand, a hydranth develops on each cut end. By cutting short pieces transverse to the long axis of such animals as hydras, the little flatworm *Planaria*, and others, two-headed animals will regenerate.

Child's theory of axial gradients. The very interesting experiments just presented, as well as a large number of similar studies on various other animals and plants, seem to indicate that the pattern of the organism is the result of certain dynamic processes. The organism appears to contain regions where there is a high rate of metabolism or oxidation and regions of low metabolism. If we consider a region of high metabolic rate as one pole and a region of low rate as another pole, then a line connecting the two poles would constitute an axis.

Now the intensity of the rate of metabolism gradually decreases along this axis from the region of high metabolism to the region of low metabolism. In other words, there is a gradient in metabolic rate. It has been observed that head or apical structures tend to develop first, and to a fuller degree of perfection,

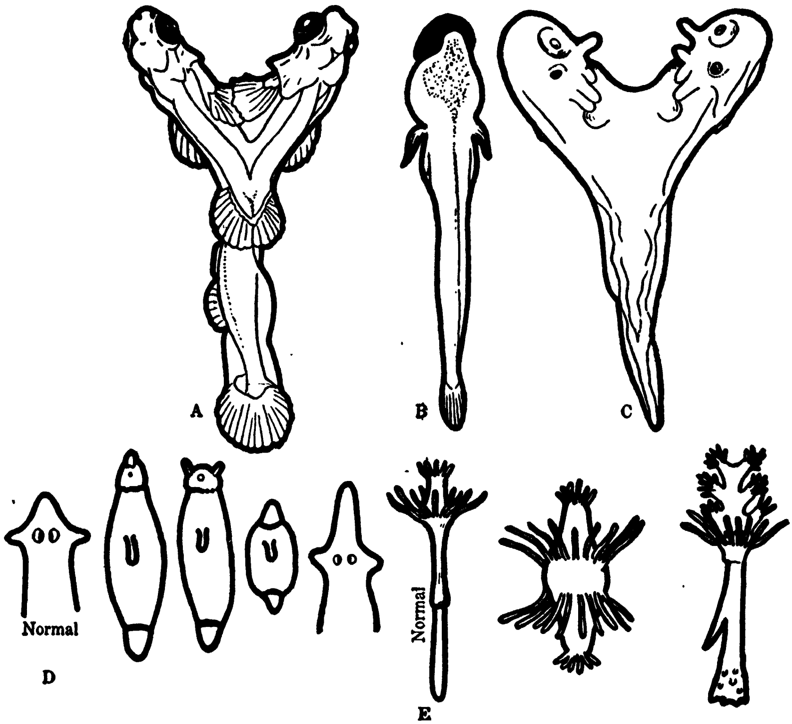


FIG. 171. Controlled development. *A*, Siamese twins of the brook trout caused by low oxygen supply before gastrulation. *B*, Cyclopia (one eye) induced in the minnow (*Fundulus*) by treatment with magnesium chloride. *C*, partial twinning in the animal *Triton*, an amphibian, caused by constricting the early gastrula. *D*, normal head of the flatworm, *Planaria*, and bizarre heads induced by keeping regenerating pieces of the animal in various solutions. *E*, normal hydroid of the animal *Corymorpha* and abnormal forms induced under experimental conditions. *A, redrawn from Stockard, American Journal of Anatomy, XXVIII, No. 2, 1921. B, redrawn from Stockard. C, redrawn from Spemann, Archiv für Entwicklungsmechanik der Organismen, XVI, 1903. D and E, redrawn from Child, "Physiological Foundations of Behavior," by permission of the publisher, Henry Holt and Co.*

in regions of high metabolism, which regions dominate and control the subordinate regions along the axis. These relations have been brought out in the experiments with *Tubularia* already mentioned. The apical end stuck in the sand received less oxygen than the free basal end. Its metabolism went down in comparison with the other end, and the gradient relations were reversed. Con-

sequently, apical structures developed on the former basal end which became the high and dominant region on a new gradient. When two hydranths formed on each end of the piece, both cut ends had theoretically the same rate of metabolism and two gradients were established with the low region in the center of the piece. The "organizer" of Spemann may owe its power to set up and control axes to a high rate of metabolism existing in the cells of the dorsal lip of the blastopore. The animal pole of the egg with the highest rate of metabolism sets up a primary gradient. Other subordinate gradients may be set up in various body levels and regions as the axis lengthens through growth.

This gradient with its subordinate axes is the quantitative dynamic pattern of the organism. It is almost impossible to conceive of the many varied chemical and physical reactions which are taking place in the protoplasm. They may vary in intensity and general nature at different places along the axis of the gradient so that in various regions (gradient levels) different end products are being formed. Changes then in the gradient relations, i.e., dynamic pattern, result in changes in the visible structural pattern of the organism.

Twins and twinning. The phenomenon of twinning is familiar to almost everyone. It is rather well known that the twins may be as "much alike as two peas"; they are of the same sex, look alike, and behave alike. Such twins are known as **identical** or **duplicate twins.** They are supposed to be the result of the breaking apart of the two blastomeres in the two-cell stage, or perhaps of a later division of the embryonic cell mass into two parts. On the other hand, there are twins who do not resemble each other so much either physically or mentally. Such twins, known as **fraternal twins,** probably came from two different zygotes. Triplets, quadruplets, and quintuplets develop from a single zygote or different zygotes. The nine-banded armadillo normally bears four offspring which are alike, and a study of this interesting animal has shown conclusively that the quadruplets are from a single zygote. There are certain wasps which lay their eggs in the eggs of butterflies. Very early the embryo wasp divides into hundreds of separate parts, each of which forms a grublike parasite in the body of the caterpillar. Finally these grubs or larvas form adult wasps, all of which owe their origin to a single egg.

Perhaps the most famous instance of multiple human births of all time is the Dionne quintuplets. Moreover, apparently all are "identical." An intensive study of them apparently indicates that three of the quintuplets have more similarities in common than the other two. Thus it is believed that the Dionnes originally came from one developing group of cells which divided, forming four separate groups. One of these four groups divided. The development of these last two groups gave rise to two very similar individuals that are different from those developing from the other three groups.

Prenatal influence and malformations. Doubtless everyone has seen or read about certain peculiar, abnormal, or malformed animals

commonly called monsters or freaks, such as Siamese twins, armless babes, headless babes, two-headed calves, and five-footed sheep (Fig. 172). In man it is estimated that 1 out of every 165 children born is malformed in some noticeable way. There is a tendency on the part of the average individual to explain these monsters and deformities as a result of the influence of the mother on the unborn babe. Thus a child born minus an arm is the result of the mother's seeing, reading

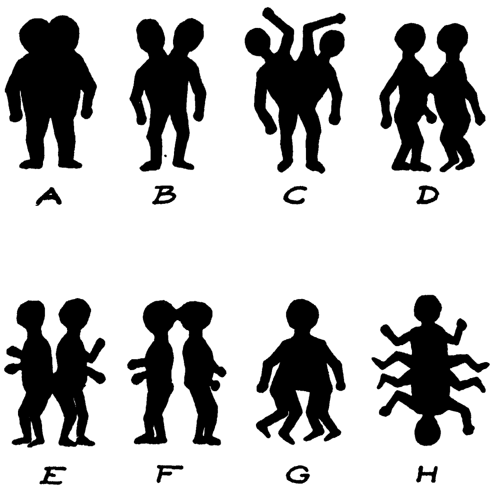


FIG. 172. Monstrosities as they occur in nature. Outline drawings of human double monsters. *From Dodds, "Essentials of Human Embryology." By permission of the author and of the publisher, John Wiley & Sons.*

about, or even hearing of an accident in which some unfortunate individual lost an arm. Reasons can be manufactured to account for all these occurrences. Further, according to this belief, if the pregnant mother listens to good music, the child will be musically inclined. If she reads good literature, the child will have literary inclinations, and so the story goes.

Modern medical men and biologists do not accept such explanations because there is no nervous connection between parent and offspring. The two nervous systems are separate and distinct. It has already been shown that the blood of the mother and that of the fetus do not mix, for the circulatory systems are separate. The anatomical relationship between offspring and parent is one of contact only. The real explanation is that such malformations may be caused by certain abnormal conditions similar to those set up experimentally, which, as we have seen, produce change in patterns.

Birthmarks belong in the same category as these other malformations.

The development of embryology. Embryology, as we have seen, is the study of the developing animal from its origin in the germ cells. It began, as did so many other sciences, with Aristotle about 384 B.C. Aristotle, without the aid of hand lens or microscope, studied and described the daily development of the chick and was much interested in the beating of the embryonic heart. Harvey and Malpighi made some studies on the chick embryo with simple lenses, and in 1677 Leeuwenhoek believed that the embryo existed as a fully formed miniature animal in the egg and that the entrance of the sperm into the egg furnished the stimulus for growth and unfolding. Followers of this school of thought were called **ovists.** Others, called **spermists,** even reported that they could see a minute human form in the spermatozoon (Fig. 173). These ideas of the ovists and the spermists constituted what is known as the **doctrine of preformation.** According to a variation of this theory all future generations are incased in the gametes of the present generation—a sort of box-in-box arrangement. Quite serious computations were made of the probable number of descendants present in Mother Eve's ovary, "at the exhaustion of which the human race would end."

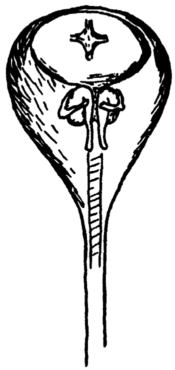


FIG. 173. Illustration of the preformation theory. Homunculus (little man) shown inside the head of a spermatozoon.

Wolff (1759) opposed this doctrine and maintained that the organs of the chick embryo gradually took form from unspecialized living protoplasm. This is the **doctrine of epigenesis,** which, in a slightly modified form, is held today. Today, it is recognized that certain regions of the egg may correspond to definite parts of the embryo, as in mosaic cleavage. Later, in 1827, von Baer, a German biologist, discovered the mammalian egg and the formation and differentiation of the primary germ layers. Von Baer is known as "the father of modern embryology." Hertwig in 1875 observed fertilization and reported the real meaning of the process. Modern embryologists have cleared up much of the mystery of development and are now busily attacking the problem of the mechanics of the process.

SUMMARY

A study of the growth and reproductive processes of plants and animals shows many points of similarity. Growth takes place by mitosis (indirect cell division), cell enlargement, and cell differentiation. In both groups of organisms there is asexual reproduction by budding, fission, sporulation, and other methods. Sexual reproduction takes place by specialized cells called gametes which fuse, forming a zygote. The zygote develops into the young embryo and finally the adult organism.

In plants the essential organs of reproduction are the stamens with the pollen and the pistil containing the ovules. Pollination of the flower takes place in various ways. The ovule after fertilization becomes the seed, which is often aided in dissemination by the fruit that develops around it.

In animals the mature gametes from the testes and ovaries may fuse to form a single-celled zygote. This zygote undergoes cleavage and gastrulation with the consequent formation of three primary germ layers, from which the tissues and organs of the adult differentiate. Development may be initiated by parthenogenesis. The form and pattern of the developing animal is apparently modified by various environmental factors.

CHAPTER XI

HOW DO PLANTS AND ANIMALS INHERIT? HEREDITY AND EUGENICS

We have already seen how living organisms are constructed, how they carry on life processes, and how the new individual originates either asexually or sexually by the union of the gametes. Man has recognized from very early times that offspring have a tendency to resemble their parents and even their grandparents. The ancient Egyptians and Babylonians evidently knew something of this principle called heredity for they left us tangible proofs in improved breeds of domestic plants and animals. The old proverb that "like begets like" does not seem to hold in every detail, since it has been discovered that two white rabbits may produce jet-black offspring, and that the offspring of a white-flowered four-o'clock pollinated by a red-flowered four-o'clock will have pink flowers. In spite of these facts and many others like them, we can still subscribe to the doctrine that "man does not gather grapes of thorns or figs of thistles," but we must also recognize that "like does not produce like, but only somewhat like." Offspring are never exactly like the parents but differ in various physical and mental characters. These differences, generally called **variations,** may be the result of ancestral inheritance, or they may be caused by differences in environment.

Sir Francis Galton, an Englishman, gathered from various sources a mass of accumulated observations on heredity and variation dealing mostly with man. Some of this material came from biologists, some from farmers and breeders, and some from general sources. This material he attempted to systematize and treat statistically. Galton's studies served mostly to focus attention on heredity and to outline the problem but did little toward solving it. His evidence lacked controlled experimental treatment and came from mere random observations. His studies lumped all like characteristics together, whether they were the result of heredity or of environment. Tallness or shortness of stature may be, in some measure, the result of either heredity or malnutrition, yet under Galton's method variations resulting from both heredity and environment received the same

interpretation. Much of his study was made on general populations rather than individuals. As we shall see, it was only when an intensive systematic experimental study of individuals was made that the real causes and the mechanism of heredity were revealed. However, credit must be given to Galton for initiating the statistical study of heredity.

Gregor Mendel was an Austrian monk who lived in a monastery in central Europe. This son of a farmer, at great sacrifice on the part of his family, was educated for the priesthood. In his training he also studied mathematics and science and proved to be a very good student. His church work was his vocation, but his hobby was science and mathematics, and particularly that science which had to do with heredity. In his monastery garden he experimented with plants and bees, and he published several papers on new varieties of bees which he had been able to produce through breeding experiments. He is best known today for his breeding experiments with plants, experiments which laid the foundation of the modern science of heredity.

Fig. 174. Gregor Johann Mendel (1822–1884). *From W. Bateson, "Mendel's Principles of Heredity," published by the Cambridge University Press. By permission of their American agents, the Macmillan Co.*

Instead of choosing large groups of plants and animals for study, he picked out one which he knew quite well. Further, he limited each study to one peculiarity or characteristic, did his own crossing or mating, and reared the resulting population through several generations. His epoch-making discoveries were the result of experiments on the common garden pea. It is well worth while to call attention here to the fact that many of our greatest scientific discoveries have been made with ordinary apparatus and commonplace materials in the hands of non-professional experimenters.

Mendel published his experiments in the *Proceedings* of the Natural History Society of Brünn in 1865 and 1866. However, no one understood or appreciated his work until 1900, when three biologists, Correns, De Vries, and Tschermak, rediscovered it. As for Mendel, he rose to the position of abbot of his monastery and became so absorbed in his new duties that his scientific studies ceased. The latter days of his life were spent in unsuccessfully combating

what he considered an unjust tax, and he died in 1884, a very much discouraged man. Today Mendel is famous not for what he did in his profession but for the achievements of his leisure-time activities.

It is interesting to contrast the method of study of Mendel with that of Galton. Galton's evidence (or data) was, in a sense, "hear-say evidence." Mendel gathered his evidence at first hand. Moreover, his experiments were controlled. Galton and Mendel had these two scientific tendencies in common: an impelling curiosity and a desire for exact measurement which can come only from the application of mathematics.

THE MECHANISM OF HEREDITY

The modern study of heredity began with the rediscovery of Mendel's reports in 1900. Starting from his reports as a basis, new investigations have shown that Mendelian principles hold true for both animals and plants. Moreover, improved microscopic and genetic methods have apparently demonstrated that the determiners of hereditary characteristics, or the **genes** as they are called by the modern student of heredity, are located in the chromosomes of the nucleus of the cell. The study of the chromosomes and their behavior, then, is the study of the hereditary mechanism.

Germplasm and somatoplasm. We have already learned that the new individual originates sexually from the union of an egg and a sperm. Accordingly, in the present discussion of heredity, we shall be concerned with determiners of hereditary characters which are transmitted by the germ cells. Just as these facts serve to focus our attention on the germ cells, so did they attract the attention and study of the early biologists. Among these was a man named Weismann, a brilliant student of heredity and embryology, who formulated the **germplasm theory of heredity,** which is sometimes called the **theory of the continuity of the germplasm.** According to Weismann, the organism is made up of two kinds of living substance or plasm, **somatoplasm** and **germplasm.** All the cells making up the body structures, such as brain, eye, stomach, liver, muscles, bone, and connective tissues, are somatic cells. The supporting tissue of the sex organs themselves is somatic. The primordial germ cells and the gametes developed in the gonads constitute the **germplasm.**

The somatoplasm which makes up the bulk of the individual lives its life cycle and dies. It is mortal. On the other hand, the germplasm is able to produce more germplasm in the form of gametes. These fuse, and the zygote thus produced may form a new individual

containing germplasm from which will be formed new somatoplasm. The somatoplasm is merely the temporary home for the potentially immortal germplasm, which, like a continuous stream, flows eternally on, receiving tributary streams of germplasm from generation to generation. (See Fig. 175.) Theoretically, germplasm not only is potentially immortal but also, as will be pointed out later, is free from any influence or contamination by the somatoplasm.

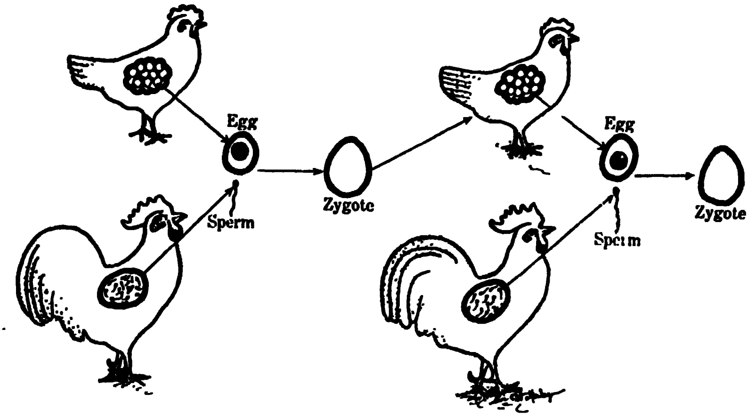


FIG. 175. Diagram illustrating continuity of the germplasm. Somatoplasm indicated by light outline and germplasm by heavy outline.

Maturation of the germ cells. Meiosis. Under usual conditions, for each kind of animal or plant, we find a constant number of chromosomes in the somatic cells and in the primordial germ cells. The chromosome numbers of certain animals and plants are listed in the following table. Change in the number of chromosomes quite often results in a change in the individual organism. Suppose that the little fruit fly *Drosophila,* which has eight chromosomes in its body cells, produced gametes with eight chromosomes in each of

CHROMOSOME NUMBERS (2*n*) OF SOME COMMON ANIMALS AND PLANTS

Animals	Chromosome Number 2*n*	Plants	Chromosome Number 2*n*
Man (*Homo*)	48	Pea (*Pisum sativum*)	14
Horse (*Equus caballus*)	60	Corn (*Zea mays*)	20
Ameba (*Entamoeba histolytica*)	6	Fern (*Dryopteris pseudo-mas*)	144
Housefly (*Musca domestica*)	12	Onion (*Allium cepa*)	16
Crayfish (*Cambarus virilis*)	200	Primrose (*Primula sinensis*)	18
Monkey (*Cebus*)	44	Cabbage (*Brassica oleracea*)	18
Cow (*Bos taurus*)	38	Radish (*Raphanus sativus*)	18

their nuclei. If these gametes fused, the resulting zygote would have sixteen chromosomes, or twice the number in the cells of the parents. But usually the gametes are the result of a process of **maturation** including **meiosis** (*meiosis*—reduction), a distinctive nuclear process in which the number of chromosomes is reduced to one-half the number found in the parent. In other words, an animal with eight chromosomes, which is the $2n$ or **diploid** (*diploos*—double) number, would have its chromosomes reduced to one-half, or four, the n or **haploid** (*haploos*—simple) number in the germ cells.

Meiosis in plants. In the plum each nucleus has 20 chromosomes, and therefore each **pollen mother cell** in the anther has this number of chromosomes. The pollen mother cell divides, forming two cells, and then each of these divides so that four cells are derived from each mother cell (Fig. 176). These cells separate and each becomes a pollen grain or microspore, which will give rise to the male gametes. If the nucleus of one of these pollen grains is examined microscopically, it will be found to contain only 10 chromosomes instead of 20, the number occurring in the pollen mother cell. The divisions of the pollen mother cell distribute its chromosomes among the daughter cells in such a way that each contains one-half the number found in the original cell. The entire process is known as **maturation** involving **reduction division** of the cells. If we wish to generalize we may say that the number of chromosomes in any pollen mother cell is $2n$, and that this number of chromosomes is reduced to n in the pollen grain by the process of maturation. A similar process takes place within the ovule in the formation of the megaspores. The megaspore mother cell, containing $2n$ chromosomes, undergoes reduction division, giving rise to four megaspores each of which contains n chromosomes. Usually but one of these megaspores functions; the other three disintegrate. The functional megaspore enlarges, and its nucleus undergoes three successive divisions, giving rise to eight nuclei (Fig. 176).

Meiosis in animals. As far as chromosomal behavior is concerned, meiosis in animals is practically the same for both the male, where it is known as **spermatogenesis** (*sperma*—seed; *genesis*—birth), and the female, where it is called **oögenesis** (*oon*—egg; *genesis*) (Fig. 177). The soma cells, the primordial germ cells, and the spermatogonia and oögonia have the diploid or $2n$ number of chromosomes. The primordial germ cells continue to multiply for a period by mitotic cell division. However, there comes a time when the individual chromosomes pair off side by side, a process called **synapsis** (*synapsis*—union. Each member of the pair is divided longitudinally to form

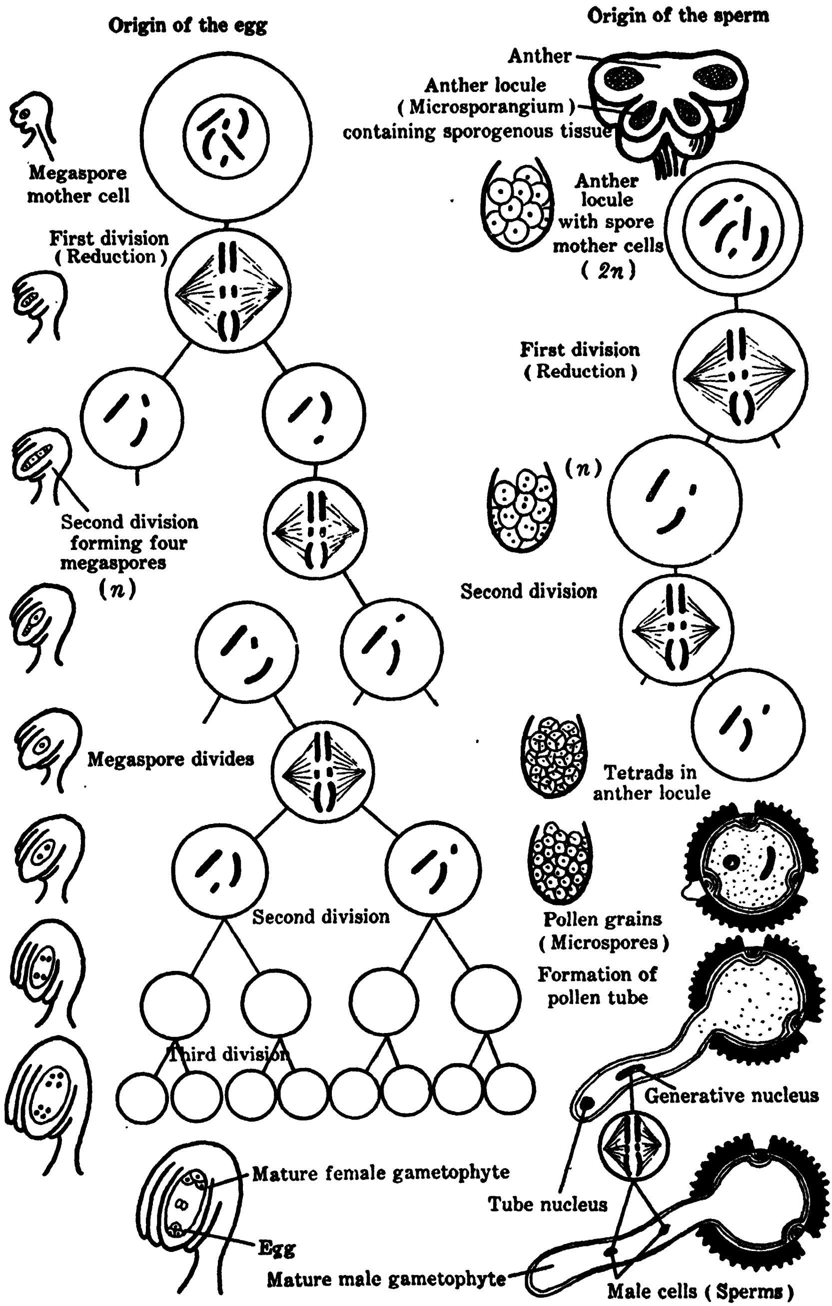


FIG. 176. Maturation. Diagram showing the maturation of germ cells of a seed plant (gametogenesis).

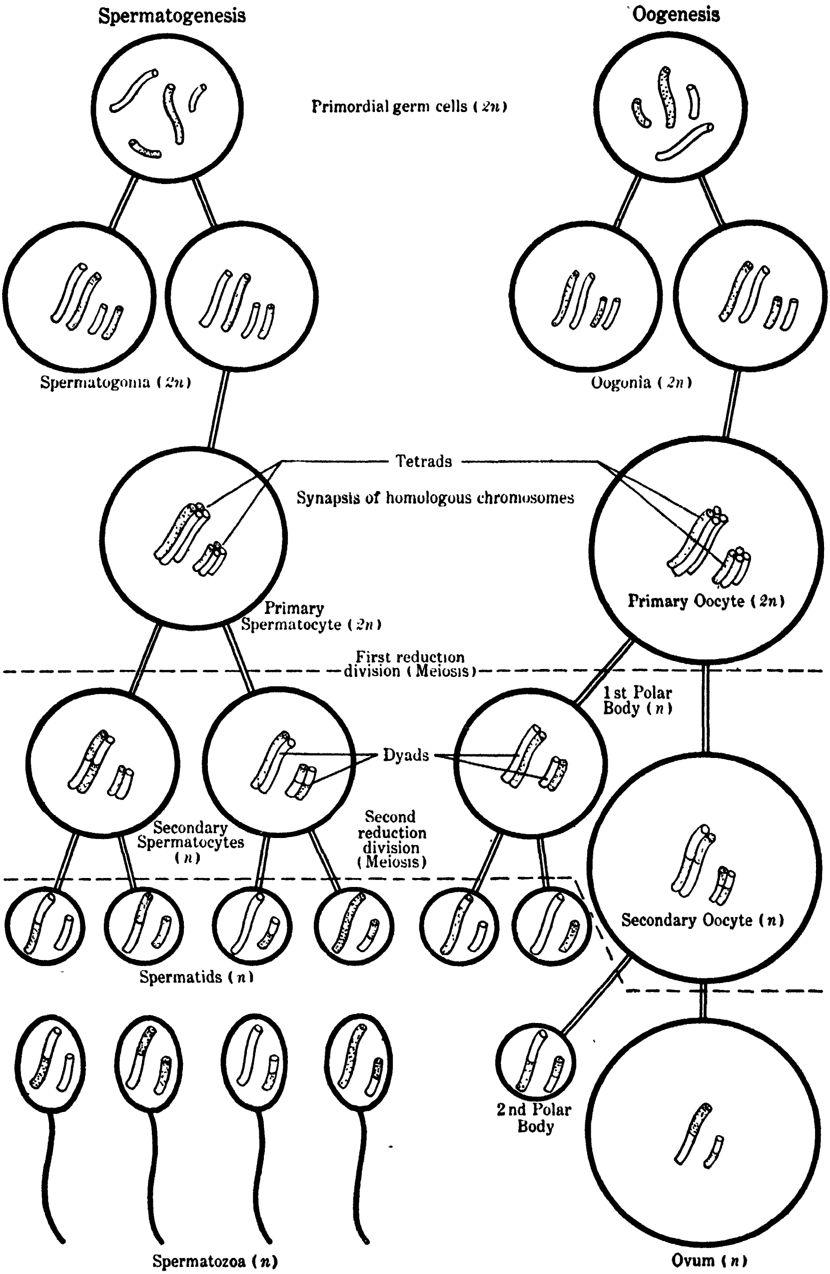


FIG. 177. Maturation. Diagram showing the maturation of germ cells of animals (gametogenesis). Stippled chromosomes represent the paternal contribution, clear chromosomes the maternal contribution. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

two half-chromosomes or **chromatids.** Thus each pair of **homologous** chromosomes would be made up of four chromatids (a **tetrad**). The germ cells are now known as the **primary spermatocytes** in the male, and **primary oöcytes** in the female. (Study Fig. 177.) This pairing is not by chance, for as we study cells more closely we find that apparently each diploid cell really has two sets of chromosomes, one paternal set contributed by the spermatozoon and one maternal set contributed by the egg. The chromosomes of each pair differ from those of the other pairs. In other words, there are in each zygote, and in every diploid cell, pairs of homologous chromosomes. If a diploid cell has four chromosomes, it will have two pairs of homologous chromosomes. The homologous chromosomes resemble each other not only in appearance, but also, as revealed by the discoveries of modern heredity, in potentialities for the same structures, the same physiological processes, and the same influence in development.

For example, suppose that there are two pairs of homologous chromosomes (four chromosomes) in the primary spermatocytes and the primary oöcytes. They arrange themselves in homologous pairs on the spindle. Each member of the pair is divided longitudinally to form four chromatids. Two chromatids (equivalent of one chromosome) go to one end of the spindle, and two chromatids go to the other end of the spindle. Recall that theoretically each cell had four chromosomes (two tetrads). Thus when the cell divides there are two cells each of which has two chromosomes or one-half the number that was in the germ cell before reduction took place. This is the **first meiotic division.** This reduction division of the primary spermatocytes and the primary oöcytes gives rise to the **secondary spermatocytes** and the **secondary öocytes.** They are similar in that they have *n* chromosomes, made up of two chromatids each. The cytoplasmic division of the primary oöcyte is unequal, so that one of the secondary oöcytes is much smaller; it is known as the **first polar body** (Fig. 177). The secondary spermatocytes and the secondary oöcytes now undergo a **second meiotic division** in which each resulting cell receives two chromatids which later will form two chromosomes. One of the daughter cells of the secondary oöcyte forms a **second polar body,** and the other forms an ovum (Fig. 177). Maturation continues. All the polar bodies disintegrate, leaving but one mature ovum with most of the cytoplasm and a rich supply of stored food for the coming offspring. All the sperm cells develop into mature spermatozoa with an equal amount of cytoplasm, though much less than that found in the surviving ovum. The spermatozoon has sacrificed food supply for motility. Thus we see how

mature n haploid gametes, the bearers of heredity and the sources of the new individual, are formed.

MENDELIAN CROSSES AND CHROMOSOME BEHAVIOR

The more intensive study of the cell and heredity since 1900 has indicated that the genes, the carriers of heredity, are located not merely in the nucleus of the gamete but actually at particular places or **loci** (*locus*—place) in particular chromosomes. Consequently the modern explanation of the hereditary mechanism is very definitely linked with chromosomal behavior and distribution.

Monohybrid cross. Keeping in mind then the process of meiosis and the facts just mentioned, suppose that we experiment with the heredity of guinea pigs. For the sake of clarity we shall *assume* that in the diploid condition there are six chromosomes present in the cells of the guinea pig. (Actually there are thirty-eight.) Suppose that we cross a **homozygous** black male (BB) with a homozygous white female (bb). When two genes in two homologous chromosomes are alike, the animal or plant is said to be **homozygous** with respect to the character in question. Suppose the genes for black (B) and the genes for white (b) to be located in corresponding loci of certain homologous chromosomes. Thus the black homozygous guinea pig would have a gene for black (B) in each of a pair of homologous chromosomes. This homozygous genic condition we would designate as BB. Similarly the guinea pig homozygous for white has a pair of homologous chromosomes in each of which there is a gene for white (b) and which pair we would designate bb. (Study Fig. 178.) At the completion of meiosis in the male, each homologous chromosome with the gene B will have gone to a different male gamete. Thus all the male gametes will carry B. A similar process will have taken place in the female except that each gamete or ovum will have a chromosome with the gene b (Fig. 178).

Fertilization takes place, and, when the zygotes have developed into adult guinea pigs, we find that all the animals are black. This generation of animals, called the **first filial generation** (*filius*—son), is designated as F_1. The parents of these animals represent the **first parental generation** or P_1. Since these F_1 individuals are mixed or **hybrids** (Bb), one might expect that they would be neither black nor white but some intermediate color such as gray. The fact that all F_1 individuals are black, even though we know that white (b) is present in the zygote, is explained by assuming that in the presence of black (B) the character white is not expressed. Thus we call

black a **dominant character** and white a **recessive character.** In the shorthand of genetics, dominant characters are represented by capital

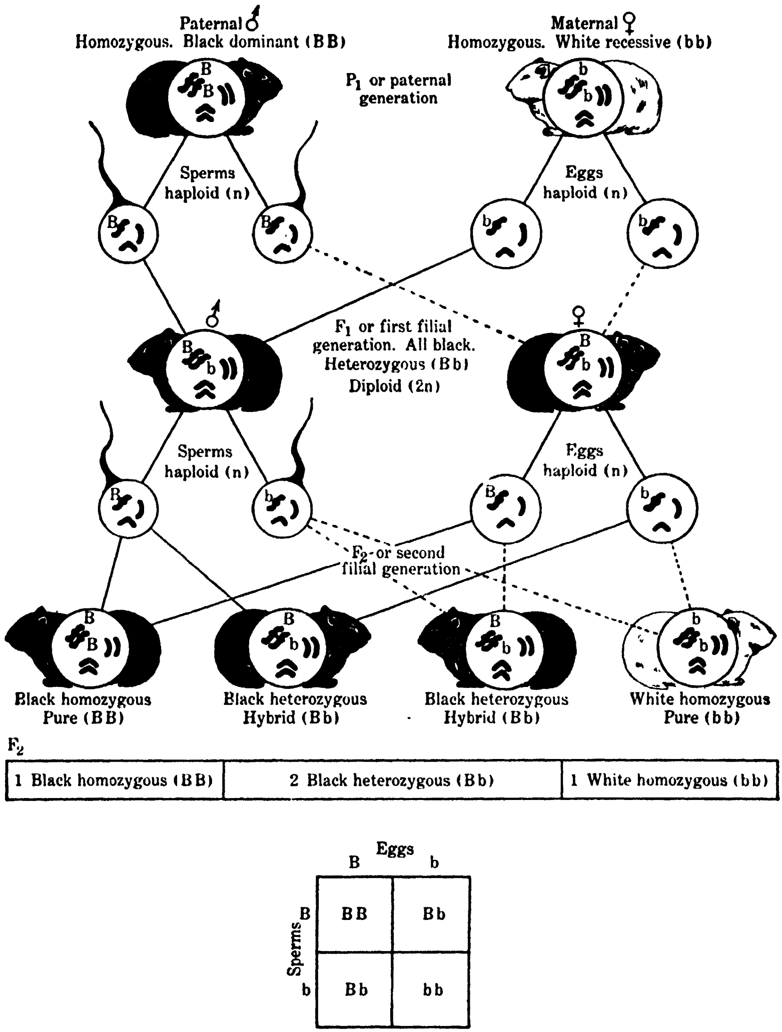


FIG. 178. Diagram of a monohybrid cross of homozygous black and homozygous white guinea pigs.

letters and recessive characters by small letters. These characters which act as alternates in inheritance are called **alleles** (*allelon*—another).

If we study the zygotes formed, it is seen that, in the pairs of homologous chromosomes we have been tracing, one paternal chro-

mosome bears the gene *B*, and in the corresponding locus its homologous maternal chromosome bears the gene *b*. All animals in the F_1 generation will have the genic make-up *Bb*. When the two genes in the two homologous chromosomes are unlike (*Bb*), the animal or plant is **heterozygous** for the character in question. Thus all the animals in the F_1 generation having the genic make-up *Bb* are heterozygous. Since black is dominant over white, all the animals in the F_1 generation will be black hybrids. (Study Fig. 178.)

Now suppose that the males and females of the F_1 generation are inbred. You will recall that the primordial germ cells are heterazygous, one chromosome having the gene *B*, and its homologous mate, in the corresponding locus, having the gene *b*. The germ cells undergo meiosis. The chromosomes normally separate after synapsis and go to different gametes, so that there are now *B* and *b* spermatozoa and *B* and *b* eggs (Fig. 178).

By chance each kind of sperm can fertilize either kind of egg. The possible combinations of male and female gametes bringing about the association of homologous chromosomes is shown as follows:

Sperm *B* may fertilize egg *B* to give a zygote *BB* (Black, homozygous).
Sperm *B* may fertilize egg *b* to give a zygote *Bb* (Black, heterozygous).
Sperm *b* may fertilize egg *B* to give a zygote *Bb* (Black, heterozygous).
Sperm *b* may fertilize egg *b* to give a zygote *bb* (White, homozygous).

Thus in this **second filial generation** (F_2) we find a ratio of three black guinea pigs to one white. However, an analysis of this ratio shows one pure homozygous black (*BB*), two hybrid heterozygous black (*Bb*), and one pure homozygous white recessive (*bb*). This ratio is the one usually obtained from a **monohybrid cross** in which there is only one pair of contrasting genes.

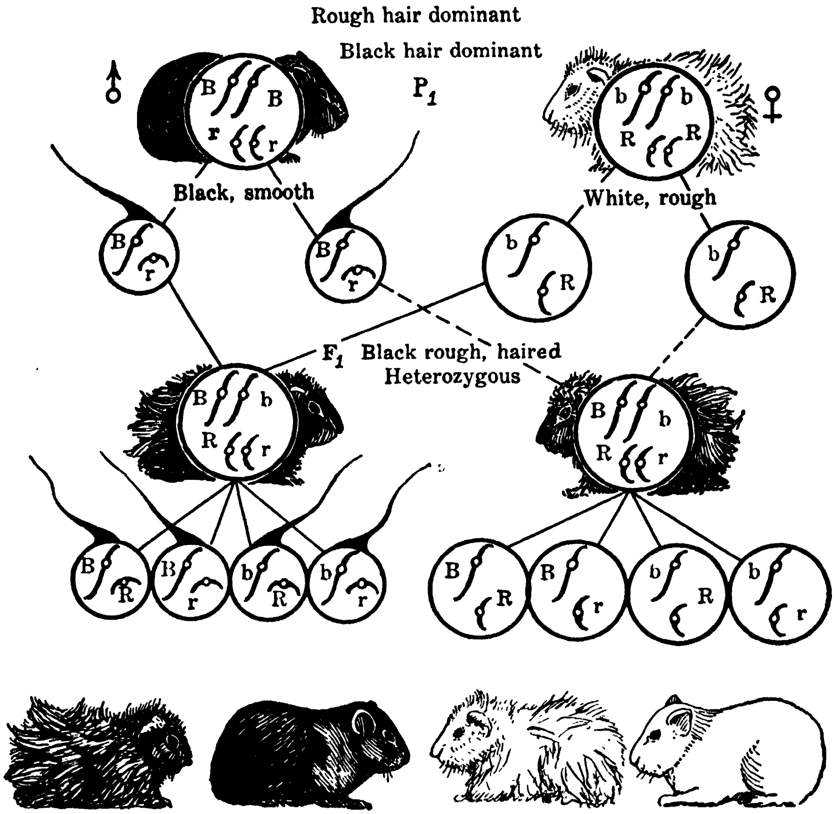
This random pairing or fusion of unlike gametes has been well illustrated by the following experiment. Suppose that we mix thoroughly 100 black marbles and 100 white marbles and then place them in two separate vessels with 100 marbles in each vessel. The mixed black and white marbles in each vessel represent the gametes, and the containing vessels represent the male and female parents. If a blindfolded person removes these marbles in pairs, each time taking one marble from each of the containers, the different pairs will be grouped approximately as follows: one-fourth of them will be black-black, two-fourths will be black-white, and one-fourth will be white-white. This is the same ratio as the one observed in the monohybrid cross of a black guinea pig with a white guinea pig. A similar test of the result of random pairing can be made by tossing coins, taking two successive tosses as a pair.

The different kinds of genic combinations found in the zygote as a result of various matings are much more easily seen by means of the checkerboard diagram. In this diagram the male gametes are usually placed horizontally across the top of the checkerboard, and the female in a vertical column to the left. The female gametes are arranged in the same descending order as the male gametes are arranged in horizontal order from left to right. The use of the checkerboard can be most easily understood by its application in the F_1 cross of the experiment just described.

		Male Gametes	
		B	*b*
Female Gametes	*B*	*BB*	*Bb*
	b	*Bb*	*bb*

The modern geneticist recognizes two general types of individuals. Those individuals which are alike *externally* with respect to the characters in question, such as *all* the *white* guinea pigs, belong to one **phenotype.** All the black guinea pigs would belong to another phenotype. However, we have seen that the black animals are not all alike genetically, that is, in their chromosomes. Some are pure or *BB*, and some are hybrid or *Bb*. In other words there are two kinds of animals, *BB* and *Bb*, as judged from the *internal* make-up. These are known as **genotypes.** Thus, if we analyze the ratio of 3:1 we find that in the "3" there are: one phenotype (external) and two genotypes, i.e., *BB* and *Bb* (internal). The "1" has one phenotype and only one genotype, for all are white and *bb*.

Dihybrid cross. The cross just described is the simplest that can be made. Suppose that, instead of a cross involving but one pair of contrasting characters (monohybrid), a cross is made between two animals having two pairs of contrasting characters, or, in other words, a **dihybrid cross.** This would involve two pairs of contrasting genes, which may be located in the same pair of homologous chromosomes or in different pairs. Suppose that male guinea pigs, homozygous for black smooth hair, are crossed with female guinea pigs homozygous for white rough hair. Black and rough are dominant. If the genes are located in different paired homologous chromosomes, the genes of the male would be represented as *BBrr* and those of the female *bbRR*. These genes are shown in different chromosomes in the diagram in Fig. 179. In the process of meiosis, homologous chromo-



F_2 ratio

9	3	3	1
9 black rough 1 BBRR 2 BBRr 3 BbRR 3 BbRr	3 black smooth 1 BBrr 2 Bbrr	3 white rough 1 bbRR 2 bbRr	1 white smooth 1 bbrr

	BR	Br	bR	br
BR	BBRR	BBRr	BbRR	BbRr
Br	BBRr	BBrr	BbRr	Bbrr
bR	BbRR	BbRr	bbRR	bbRr
br	BbRr	Bbrr	bbRr	bbrr

FIG. 179. Diagram of a dihybrid cross of homozygous black, smooth-haired male and homozygous white, rough-haired female guinea pigs. Genes are represented by small circles in the chromosomes.

somes separate and go to different gametes. Hence the spermatozoa would be represented as *Br* and the ova as *bR*. These gametes in fertilization would form zygotes *BbRr* from which would develop the F_1 generation. All the F_1 guinea pigs would have rough black hair, the dominant characteristics. If the genes segregate independently of each other and by chance, these F_1 animals, both male and female, would have the following possible combinations of gametes: *BR, Br, bR, br.* (Study Fig. 179.) If these hybrid F_1 animals are inbred and the various types of spermatozoa fertilize, by chance, various types of ova, the resultant phenotypic ratio in the F_2 generation will be 9 Black Rough, 3 Black smooth, 3 white Rough, 1 white smooth. This cross is shown by the checkerboard in Fig. 179.

Present-day Mendelism

The basic principles of heredity discovered by Mendel and illustrated by the crosses just described are in use today in a modified and extended form as a result of important discoveries made possible by improvement of instruments and technique and by the concentrated study of many brilliant, hard-working biologists.

Sex determination and sex linkage. From ancient times to the present, probably no phase of biology has been the subject of more speculation than sex determination. All sorts of wild theories have been advanced. Some held that diet determined the sex of an individual before fertilization. Another theory maintained that the offspring would be of the sex of the older and stronger parent. Some thought that a very fresh egg or one which was fertilized soon after ovulation would produce a female, whereas an older egg if fertilized would produce a male. Other theories, equally fantastic, were held, such as the theory that one testis produced female-determining spermatozoa and the other male. Today biologists believe that sex is determined at the time of fertilization by the types of gametes, but that the ultimate development of the sexual characteristics of the individuals of certain groups may be changed by various environmental factors.

In 1902 McClung reported that in the testes of certain grasshoppers there was an odd-shaped, apparently unpaired chromosome which he thought was a sex determiner. This opened a new field of investigation. Later it was found that in the cells of *Drosophila* there were eight chromosomes. The members of three pairs of these were visibly similar, and the members of the remaining pair were dissimilar in the male and similar in the female. In the male, one chromosome

(Continued on page 327)

Trihybrid Cross. In **trihybrid crosses,** organisms having three pairs of contrasting characters are crossed, producing offspring in the F_1 generation which are hybrid or heterozygous for three pairs of characters. Such a cross can be worked out by the checkerboard, applying the same principles already stated, except that now there will be eight different types of genic combinations or gametes in the F_1 generation, which may produce sixty-four types of individuals in the F_2. Suppose that a cross is made between homozygous Tall Smooth Yellow, *TTSSYY*, and dwarf wrinkled green peas—*ttssyy*. If tall (*T*), smooth (*S*), and yellow (*Y*) are dominant, the F_1 generation would exhibit these characteristics. The gametic combinations possible in the F_1 hybrids would be *TSY*, *TSy*, *TsY*, *Tsy*, *tSY*, *tSy*, *tsY*, *tsy*. This is worked out in the accompanying checkerboard and gives the following phenotypic ratio for the F_2 generation.

27 TALL, SMOOTH, YELLOW
9 TALL, SMOOTH, green
9 TALL, wrinkled, YELLOW
9 short, SMOOTH, YELLOW
3 TALL, wrinkled, green
3 short, SMOOTH, green
3 short, wrinkled, YELLOW
1 short, wrinkled, green

Female Gametes \ Male Gametes	*TSY*	*TSy*	*TsY*	*Tsy*	*tSY*	*tSy*	*tsY*	*tsy*
TSY	*TSY* *TSY*	*TSy* *TSY*	*TsY* *TSY*	*Tsy* *TSY*	*tSY* *TSY*	*tSy* *TSY*	*tsY* *TSY*	*tsy* *TSY*
TSy	*TSY* *TSy*	*TSy* *TSy*	*TsY* *TSy*	*Tsy* *TSy*	*tSY* *TSy*	*tSy* *TSy*	*tsY* *TSy*	*tsy* *TSy*
TsY	*TSY* *TsY*	*TSy* *TsY*	*TsY* *TsY*	*Tsy* *TsY*	*tSY* *TsY*	*tSy* *TsY*	*tsY* *TsY*	*tsy* *TsY*
Tsy	*TSY* *Tsy*	*TSy* *Tsy*	*TsY* *Tsy*	*Tsy* *Tsy*	*tSY* *Tsy*	*tSy* *Tsy*	*tsY* *Tsy*	*tsy* *Tsy*
tSY	*TSY* *tSY*	*TSy* *tSY*	*TsY* *tSY*	*Tsy* *tSY*	*tSY* *tSY*	*tSy* *tSY*	*tsY* *tSY*	*tsy* *tSY*
tSy	*TSY* *tSy*	*TSy* *tSy*	*TsY* *tSy*	*Tsy* *tSy*	*tSY* *tSy*	*tSy* *tSy*	*tsY* *tSy*	*tsy* *tSy*
tsY	*TSY* *tsY*	*TSy* *tsY*	*TsY* *tsY*	*Tsy* *tsY*	*tSY* *tsY*	*tSy* *tsY*	*tsY* *tsY*	*tsy* *tsY*
tsy	*TSY* *tsy*	*TSy* *tsy*	*TsY* *tsy*	*Tsy* *tsy*	*tSY* *tsy*	*tSy* *tsy*	*tsY* *tsy*	*tsy* *tsy*

of this peculiar pair is a straight rod-shaped chromosome designated the X-chromosome, and the homologous chromosome, which is hooked at one end, is called the Y-chromosome (Fig. 180). Thus, in the males there are three pairs of chromosomes called **autosomes,** plus this XY pair called **sex chromosomes.** In the female there are also three pairs of autosomes and two X-chromosomes or sex chromosomes. Experimentation has shown that these sex chromosomes play a part in determining sex and heredity.

If we study large random groups of populations of various animals, we find that females and males are produced in approximately equal

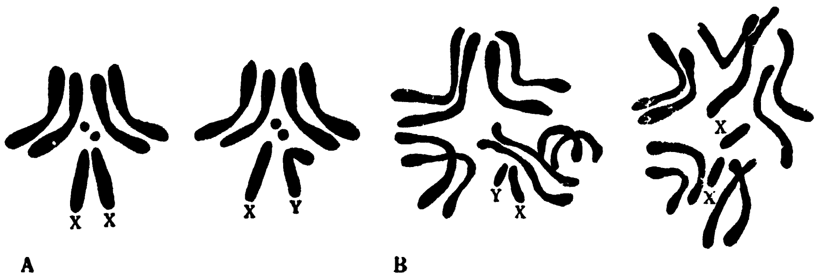


FIG. 180. The sex chromosomes of *Drosophila* (A) and the fly, *Caliphora* (B). *A, after Morgan and others. B, redrawn from Wilson, "The Cell in Development and Heredity." By permission of the publisher, the Macmillan Co.*

numbers, as would be expected in the light of the following experimental evidence. All the female gametes should be alike in regard to sex chromosomes, each containing one X-chromosome. On the other hand, there would be two types of male gametes, one containing an X-chromosome and one a Y-chromosome. In fertilization, half the X female gametes might be fertilized by X spermatozoa to produce XX zygotes which should grow into females. Recent discoveries indicate that the Y-chromosome is not necessary for the differentiation of male characters, but that the real difference between the two sexes is caused by the number of X-chromosomes present in relation to the number of autosomes, i.e., XX in the female and a single X in the male. However, when the Y-chromosome is missing in *Drosophila,* the fly will be a sterile male.

For years Morgan, a famous biologist, had studied many generations of fruit flies (*Drosophila*) which had red eyes. One day he found a white-eyed male fly among all the other newly emerged red-eyed brothers and sisters. With the true scientist's bent for experimentation, he crossed this white-eyed male fly with a red-eyed

female. However, he found nothing peculiar in the expected ratios obtained from the cross until he discovered in the F_2 generation that all the white-eyed flies were males! Normally there should have been approximately as many white-eyed females as white-eyed males.

FIG. 181. Thomas Hunt Morgan (1866–1945). *Photograph furnished by William Huse, California Institute of Technology.*

It was plain that here was a problem in which sex is involved. As previously pointed out, other investigators had advanced the suggestion that sex was determined by the peculiar pair of sex chromosomes which had been seen in the cell. All these lines of evidence being taken into consideration, the hypothesis was advanced that this peculiar hereditary problem could be explained by assuming that the genes for eye color were in the sex chromosomes, in fact, only in the X-chromosomes. The Y-chromosome was assumed to carry no factors.

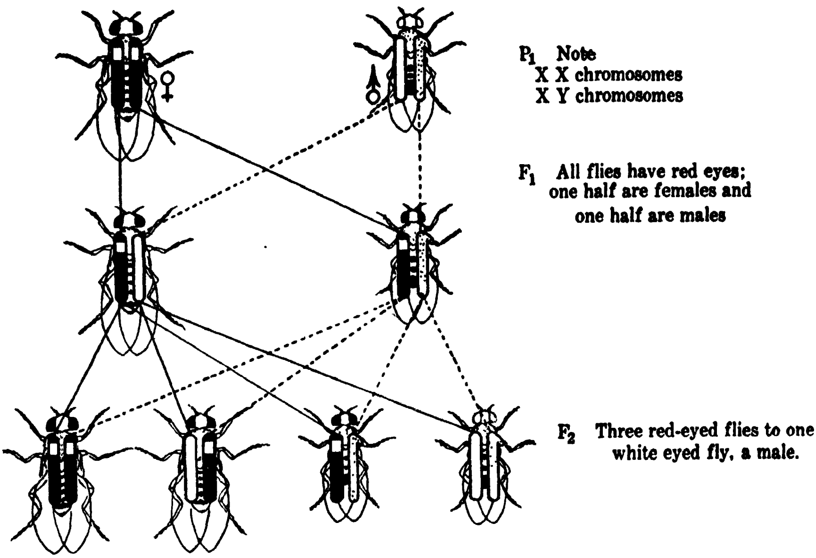
However, the method of science demands that assumptions or hypotheses must be subjected to more experimentation and proved by more evidence than can be gathered from just one experiment. Accordingly, Morgan continued his search for more evidence. He crossed a white-eyed male with heterozygous females of the F_2 generation, and from this cross white-eyed female flies appeared.

Now he was in a position to make the final, crucial experiment—crossing the white-eyed females with red-eyed males. If his assumptions were correct, there should be both white-eyed and red-eyed flies in the F_1 generation, and there should be both male and female white-eyed flies in the F_2 generation. There were.

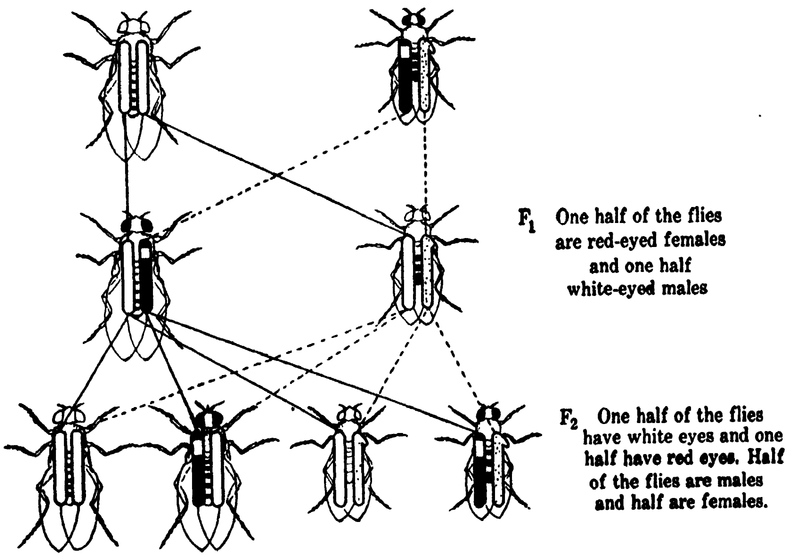
Here we see the method of science, which gathers evidence from all sources, makes assumptions or hypotheses, but, and more important, seeks to substantiate or prove these hypotheses by further experimental objective evidence or data.

Suppose that we analyze Morgan's experiment. Let us assume, as Morgan did, that the genes for red eyes and white eyes are located in the X or sex chromosomes. Red is dominant. Suppose a red-eyed female to be crossed with a white-eyed male. The F_1 generation will all be red-eyed, and one half of the flies will be males and the other half females (Fig. 182). If the males and females of the F_1 generation are mated, the F_2 generation will show the expected Mendelian ratio of 3 red-eyed flies to 1 white-eyed fly. However, all the white-eyed flies will be males (Fig. 182).

If a homozygous, white-eyed female is mated with a homozygous, red-eyed male, instead of a typical Mendelian F_1 generation in which all the flies have red eyes, we find that half the flies have red eyes and half have white eyes. Further, this ratio is divided along sex lines, for the red-eyed flies are females, and the white-eyed flies are males. Apparently the white-eyed male is the result of receiving from the mother an X-chromosome having a gene for white, and, since the Y-chromosome apparently has no gene for eye color, the males have white eyes. The female flies receive the gene for red eyes in an X-chromosome from the father, which is dominant over the recessive gene for white eyes found in the other X-chromosomes received from the mother. When these F_1 flies are inbred, instead of the 3:1 ratio expected in the F_2 generation, half the flies have red eyes and half have white eyes. Further analyses by breeding of the F_2 generation show that only one-fourth instead of one-half of the flies are heterozygous for eye color. This change in inheritance can be explained on the basis of **sex linkage** and a study of the distribution of the sex chromosomes (Fig. 182).



A. Results of crossing a red-eyed female fly (*Drosophila*) with a white-eyed male.



B. Results of crossing a white-eyed female fly (*Drosophila*) with a red-eyed male.

FIG. 182. Diagram showing sex linkage in *Drosophila*. Note that eye color follows the sex chromosomes and therefore is sex-linked. *Adapted from various sources.*

Certain genes, if located in the sex chromosome, will bring out characteristics necessarily associated with sex, and they are known as **sex-linked** characters. Such characters are not confined to modifications of sexual structure, such as the type of gonad, but may include eye color, color blindness in man, and others, depending upon the animal. Other factors often associated with sex such as the difference in plumage between male and female chickens, the usual

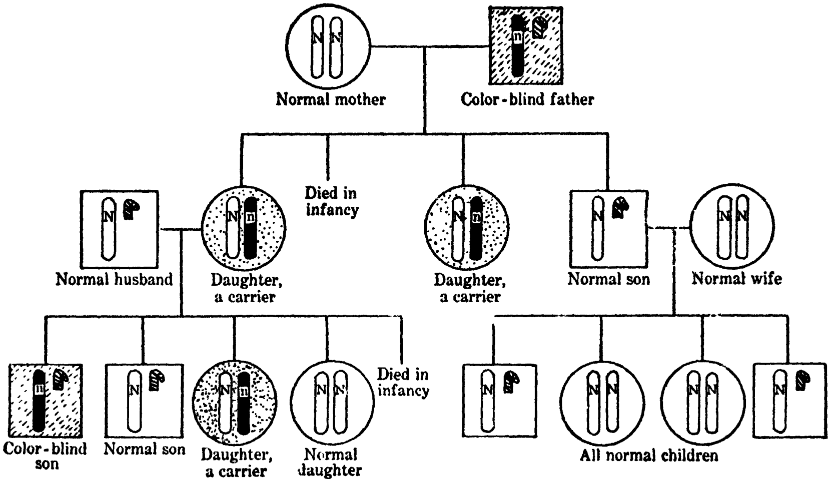


FIG. 183. Diagram illustrating the inheritance of color blindness, a sex-linked character. A carrier is a heterozygous individual whose normal gene is dominant over the defective gene.

absence of a beard in woman, as well as certain differences in nervous temperament, are known as **sex-limited** characters. Sex-limited characters depend for their expression upon the presence or absence of the sex hormones. These phenomena have been discussed previously in connection with hormones (page 187).

Color blindness, or the inability to distinguish different colors, is an example of sex-linked inheritance in man. Usually there are many more color-blind males than females, since the defective gene is in an X-chromosome and the females, if they are color blind, must be homozygous for the defective gene—the one affecting color vision. A mother apparently may have normal color vision, but if one of her X-chromosomes has a defective gene she may be heterozygous in this respect. She will produce some gametes having a normal X-chromosome and some having a defective X-chromosome. If the father is normal, he will produce normal X-gametes and Y-gametes, but any

son receiving the defective X-chromosome from the mother and the Y-chromosome from the father will be color blind (Fig. 183). On the other hand, if a color-blind male is mated to a homozygous normal-visioned female, all the offspring will have normal vision, but the daughters will carry the defective genes.

Simple linkage and crossing over. The phenomenon of sex linkage just discussed not only is interesting in itself but also definitely indi-

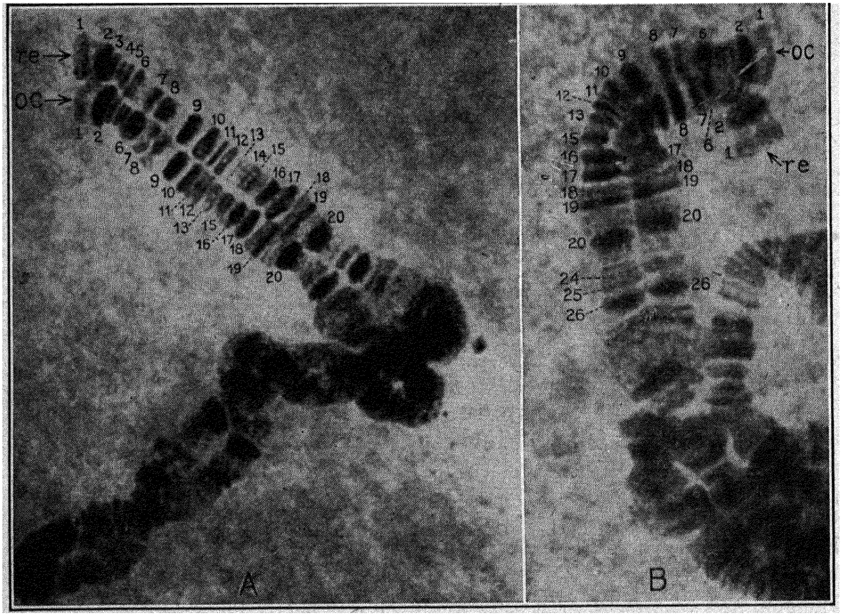


FIG. 184. Photograph of a pair of chromosomes from the salivary glands of a hybrid insect. Note the apparently similar bands in the paired chromosomes which have been appropriately numbered. *Photograph furnished by C. W. Metz.*

cates that the genes follow the chromosomes. As has been pointed out, the genes are not like many ultramicroscopic marbles confined in the nucleus of the cell by the nuclear wall but are apparently located on the chromosomes. In a sense, they make up the chromosomes. Moreover, in the light of modern investigation, they seem to be arranged in a linear order along the length of the chromosome, resembling submicroscopic beads strung on a loose string (Fig. 184). If they are on the chromosomes, do they segregate independently at random, or do they always follow the chromosome? Apparently there is some independent segregation, but not quite so free as Mendel stated. It is believed that the segregation of the genes takes

place after synapsis at the time of the meiotic divisions when the homologous chromosomes are separating from each other. It may be recalled that each chromosome divides longitudinally to form two chromatids. Two chromatids, one from each chromosome of the pair, may form what is known as a **chiasma** (from the Greek letter χ). When the chromosomes separate, the chromatids may break at the region of contact. In this way parts of each chromatid, and therefore of each chromosome, may be interchanged, and thus, in a sense, "new" chromosomes are eventually formed (Fig. 185). This exchange of parts of the chromatids of homologous chromosomes with their contained genes is known as **crossing over.** The genes that formerly occupied definite loci in the original chromosomes now occupy corresponding loci in the new chromosomes.

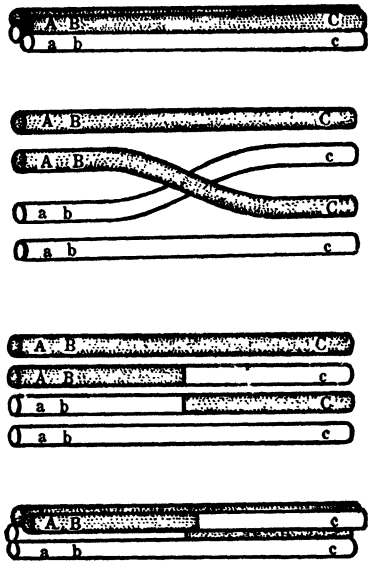


FIG. 185. Diagram showing simple linkage and crossing over between two chromatids. In pairing (synapsis), two chromatids of homologous chromosomes may be twisted together. When they separate (meiosis), the segments containing *A* and *B*, since they are close together in the chromatid, do not separate and so do not exchange places with *a* and *b*. Note that the segments containing *C* and *c* have interchanged. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

Now, if the genes are arranged in linear order as the chromosome map of *Drosophila* seems to indicate, genes located farther apart in the chromosomes are more likely to move to the homologous chromosomes when they separate than are those which are closer together. The frequency of these genic exchanges may be used as a measure of the actual distance between genes. Characters then may be associated in inheritance in what is called **linkage,** the degree of linkage depending upon the distance of the respective genes from each other.

Since the genes are carried on the chromosomes, there will be as many linkage groups as there are chromosomes. The foregoing discussion is of interest principally because it affords an explanation of the mechanism of genic segregation. The frequency of crossing over reveals the relative location of the genes, as may be shown in

chromosome maps. It explains some of the divergences in expected Mendelian ratios.

We have already seen that sex linkage and simple linkage will change the original Mendelian concept of absolute freedom of the genes in segregation and, therefore, the ratios usually expected on the basis of the former Mendelian interpretation. Accumulated data from various experiments indicate that other conditions exist to modify and extend Mendel's original concept.

Other complications of Mendelism. We have seen that sex linkage, crossing over, and simple linkage may change the ratios expected in both the F_1 and F_2 generations. In addition to these variations in Mendelian heredity, other complications have been discovered which modify the usual expected results. Some of these conditions or examples will be briefly described.

Non-dominance. If races of red and white four-o'clocks are crossed, the flowers in the F_1 generation will be neither white nor red, but pink. In the F_2 generation one-fourth of the flowers will be red, one-fourth white, and two-fourths pink. These pink flowers are heterozygous. Apparently neither red nor white is dominant.

FIG. 186. Inheritance in a mulatto family. *Photograph furnished by C. B. Davenport.*

Cumulative genes. Briefly and simply the case of cumulative genes is this. Certain characteristics vary in the intensity of expression in accordance with the number of dominant genes present for that character. Nilsson-Ehle of Sweden found that two varieties of wheat, one of which had white grains and the other reddish brown, differed by three independent pairs of genes. When the two varieties were crossed, the F_2 generation produced wheat which exhibited six different shades of color ranging from white to red, the intensity of color depending upon the number of dominant color genes present. Some such hereditary arrangement as this may account for color gradations as a result of crossing negroes and whites (Fig. 186).

Lethal genes. Breeding experiments show that there are certain genes that begin to function early in the life of the animal or plant. It sometimes happens that some of these genes, which we may designate as n, are defective or lack something necessary for the development of certain structures. Such genes are called **lethals** (*letum*—death). If a normal gene designated as N is present in one chromosome of the pair, the combination will be Nn, and a normal plant or animal will develop. If, however, the organism is homozygous for lethals, or nn, it will fail to develop. Naturally the absence of certain phenotypic classes of plants or animals in either the F_1 or F_2 will result in a different ratio from the one expected. Lethal genes have been found in certain lines of plants and animals such as snapdragons, primroses, *Drosophila*, mice, guinea pigs, and man.

Various other modifications of Mendelian heredity have been found through modern experimentation, in the light of which we must change our views of the simplicity of the process. The three great principles established by Mendel which apparently still hold today are the principle of distinct units (genes), the principle of segregation, and the independent assortment of the genes.

Genes

Today there is very meager evidence as to what a gene really is. It has been well said that "genes are known more by what they *do* than by what they *are*." Genes are thought to be large, highly complex, protein molecules. They may act like enzymes to speed up or retard chemical actions or they may cause the production of enzymes. Sometimes they may resemble hormones in their action. These chemical substances are relatively stable, for they can be handed down from generation to generation in a practically unchanged condition. Moreover, they are capable of reproducing or multiplying themselves.

Sometimes genes may undergo a change and produce new characters, in a plant or animal, which will breed true through successive generations. Such changes are known as **mutations** (*mutare*—to change) or **sports.** The white-eyed fly was a mutation. About 1800 a New England farmer found a short bow-legged male lamb in his flock of long-legged sheep, from which he developed a race of short-legged sheep, which, as Walter suggests, proved a real labor-saving device in that it was now possible for the sheep raiser to build lower fences than formerly (Fig. 187). Some other new varieties of animals that have arisen by mutation are hornless Hereford cattle, which arose from a mutant in a herd of Herefords at Atchison, Kansas, in 1891; tailless dogs and cats; and chickens with bare necks.

In addition to the changes that may be brought about in an animal or plant by mutation, other new characteristics may appear as the result of changes in the chromosomes. Many changes in plants

formerly ascribed to genic change are now known to be the result of chromosomal change. Thus in plants there sometimes occurs what is known as **polyploidy** (*polys*—many), a condition where, instead of $2n$ chromosomes being present, there may be three sets of chromosomes ($3n$), or $4n$ or even more. Some of the polyloid plants have larger and much-thickened stems; the leaves also may be larger, broader, and darker green. Other differences may be noticed in flower and fruit. Thus there have appeared new varieties of poppies,

FIG. 187. Mutation in sheep. Sheep with normal legs at the right and short-legged Ancon sheep (mutant) at the left. *Photograph furnished by Dr. W. Landauer, University of Conn.*

double petunias, giant primroses, tobacco plants with seventy leaves instead of twenty, and many other variations too numerous to list here.

Another cause of change in animals and plants is brought about by shifts of parts of chromosomes. Thus a portion of a chromosome may break off and be lost **(deficiency)**; or it may attach itself to another chromosome **(translocation)**; or it may even reverse its position within the chromosome **(inversion)**. Such changes may take place in nature or may be the result of the action of X-rays or other agents which bring about genic change. It has been found that the application of the drug colchicine may induce polyploidy in plants. When it is understood that, in addition to the changes just described, mutations may occur in the genes in these added chromosomes and chromosome pieces, some idea can be gained of the complexity of the mechanism of variability in nature.

The discovery of the giant chromosomes of the salivary glands of some insects has made possible the detection of many of the changes just listed. By means of the bands of varying width which run across the chromosomes, geneticists have been able to identify specific regions in certain chromosomes (Fig. 184). Thus, by using these bands as landmarks, they can readily detect such changes as translocations, deficiencies, and inversions.

At the present time there is no conclusive evidence as to the cause of genic and chromosomal changes in nature. Experiments apparently have shown that genic changes may be induced by X-rays. Something like this may take place in nature from natural radiations. Other evidence indicates that extremes of temperature may bring about mutations, but the problem is far from solved.

How the gene works is an interesting question and one that can be answered only hypothetically at present. However, it seems very certain that the influence of a particular gene is not necessarily restricted to a definite part of the body but may affect the entire organism. On the other hand not every character is the result of the action of a single gene, as we may have thought, but probably most characters are the result of the interaction of many genes. For example, Jennings points out that in *Drosophila* at least "fifty pairs of genes cooperate to produce the usual red color of the eye." Some genes may lay the foundation for the eye itself, after which others lay a basis for color, to which others add the proper materials for pigment. Any defect or change in one of these fifty genes will mean a change in the expected or "normal" structure of the eye. The pattern of an organism, then, is not the result of an accumulation of thousands of separate discrete particles into a "genetic mosaic or a piece of animated tiling," as East put it, but comes about rather as the result of the interaction of groups or "packets" of these chemical particles which we call genes. As a consequence, heredity is not such a simple phenomenon as a monohybrid cross might lead us to believe, but an unfolding process in which "a gene has manifold duties and numerous genes contribute their quotas toward the fulfillment of a seemingly simple task." Further, what any gene or groups of genes may produce depends not only upon their own constitution but also upon the environmental conditions.

ENVIRONMENT AND HEREDITY

We have just pointed out that there are many influences which affect various genic combinations and, therefore, the heredity of animals and plants. It would seem, however, that, even in spite of the

diverse behavior and arrangement of genes, they are responsible for what the young organism *may* become. But, on the other hand, what influences, if any, do the surrounding external conditions or environment have on the development of the individual plant or animal? With respect to this question there have grown up two schools of thought. One group holds that heredity is everything and environment is comparatively negligible, and that whatever the organism is to be and will be has been predetermined by its genes. Another group maintains that environment is everything and heredity is of little importance. As usual, the truth lies somewhere between the extremes. We have already examined some experimental objective evidence with respect to heredity; now, in turn, let us look for data which might indicate environmental influence.

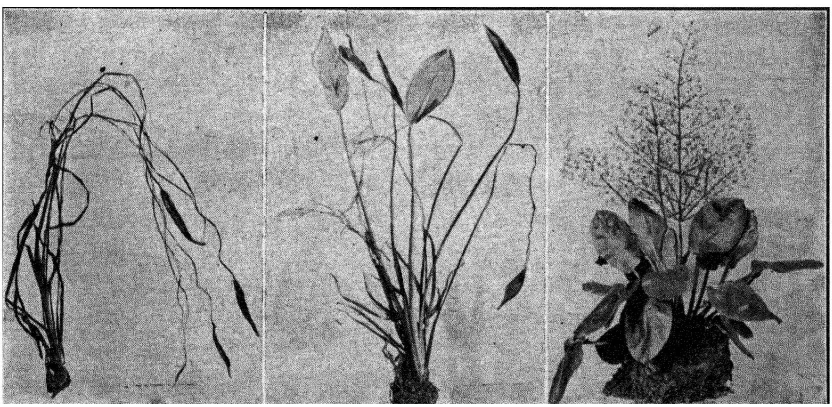
Acquired characters. We have been discussing heritable characters which, theoretically, owe their origin to genes located in the germplasm. How these characters express themselves, in many cases, depends upon the surrounding environment. We have pointed out that heritable changes in characteristics, i.e., mutations, chromosomal reconstruction, and chromosomal duplications, may be brought about by changes in the gene or genes caused by certain environmental factors such as X-rays, or they may be variations arising from unknown causes within the organism. For the man of the street, one of the vexing questions of heredity today is: can variations or changes in structure which affect the somatoplasm, such as loss of limbs, body scars, blindness, and other acquired characters, be handed on to the succeeding generations? Can special training in various arts, in religion, in social attitudes, be made a part of the heritage of the next generation? "Can nurture as well as nature be transmitted?" The answer to this question is of real importance to plant and animal breeders and to physicians, sociologists, religious workers, and educators who are interested in man's physical and spiritual growth.

From the earliest time until about 1875, it was generally believed that acquired characters could be inherited. Lamarck (1744–1829) used this idea to explain evolution, and Darwin also incorporated it in his explanation of evolution. However, some doubt gradually arose as to the validity of the belief, and finally Weismann, about 1875, presented convincing arguments against the inheritance of acquired characters. It has been commonly observed that one-armed and one-legged individuals can become the parents of normal children; that the beautifully scarred and tattooed barbarians beget

unmarred offspring; that dehorned cattle produce calves which later develop horns. The offspring of trees misshapen by the wind grow normally in sheltered places. Weismann clinched the argument by a controlled experiment. He cut off the tails of mice for twenty-two generations and found that the tails of the mice in the last generation were as long as those of the first. Later he elaborated his views by pointing out that there is no mechanism to transmit somatic changes to the germ cells. Each germ cell is an independent unit in the body. According to Castle, "germ cells are guests in the body, not members of the household."

In recent years there has been some experimental work which indicates that this question has not been settled conclusively, but the interpretation is too much open to controversy to be discussed here. Conklin well says that "few questions have been discussed so fully and so fruitlessly as this." The one unfortunate aspect of the whole situation seems to be that there has resulted a type of germplasm *dogma* which has ruled out *any* environmental effect. According to this theory, the organism's structure, function, and life reactions are immutably fixed and determined by the germplasm.

Plant response to environmental changes. There is a common greenhouse plant, a Chinese *Primula,* which, if grown at a temperature of 55–65° F., will produce red flowers generation after generation. If, however, the plant is grown at a temperature of 95° F., it



A *B* *C*

FIG. 188. Results of change in environmental conditions. Water plantain (*Alisma plantago-aquatica*). *A,* plant growing completely submerged in water. *B,* plant only partially submerged. *C,* plant growing on wet soil but completely emerged. *Photographs A and B by Mrs. Anna Wright. C, by W. E. Rumsey.*

will bear white flowers and will continue to have white flowers as long as it is kept at high temperature. If restored to low temperature, it will again produce red flowers. Emerson found that color in maize plants not only has an hereditary background but also is influenced by environment. Plants which have red leaves and other red parts remain red if grown in the sunlight; if grown in the shade these parts become green. Remember that the same genes are present under both conditions. Emerson found further that some varieties of green plants if grown on poor soil tend to be red. Collins describes a mutant variety of barley which has no chlorophyll if grown at a temperature below 45° F., but if grown at a temperature above 65° F. the plants are green. Striking results of changed environmental conditions are shown in Fig. 188. Klebs grew the plant *Sedum spectabile* under white and blue light. More than 20,000 flowers were subjected to various kinds of light as well as to changed conditions of temperature, moisture, and food. As a result, the plants varied in number of stamens, in number of flower buds, and in the amount of certain chemical substances. These experiments and many others show that what a plant *may* do in a given environment depends upon what genes are present. However, what these genes *will* produce depends on the environment.

Animal response to environmental changes. The following selected examples show that animals as well as plants can be changed and modified by environment. In *Drosophila* extra legs or branched legs are found in a mutant variety of fly if the flies develop in low temperatures. Goldschmidt, by artificially controlling the temperature, has been able to produce a whole series of different patterns of the butterfly *Vanessa io*. Other investigators have been able to change the color and pattern of moths by feeding some of the young on oak leaves and others on walnut leaves. If certain green parrots of South America are fed on the fat of catfish, their plumage becomes a variegated mixture of red and yellow. The axolotl is a salamander, one of the Amphibia, and for a long time it was considered a distinct species. It has prominent red external gills, a rather thick body, and a flattened tail adapted for swimming (Fig. 189). In this condition it may become sexually mature, rear its young, in fact live out its entire life span. Now if this axolotl is deprived of water, a tremendous change takes place. The gills disappear and the form of its body changes in practically every detail. Indeed, this animal is so different from the axolotl phase that for many years it had been considered an entirely unrelated animal called *Ambystoma*—an amphibian version of Dr. Jekyll and Mr. Hyde.

Stockard found that, if the developing eggs of the common sea minnow (*Fundulus*) were placed in solutions of various magnesium salts, as many as sixty out of a hundred of these minnows developed only one eye instead of the usual two. By other methods he has been able to produce three-eyed fish, double-headed fish, and various other strange forms (Fig. 171). Child has shown that, if the environment

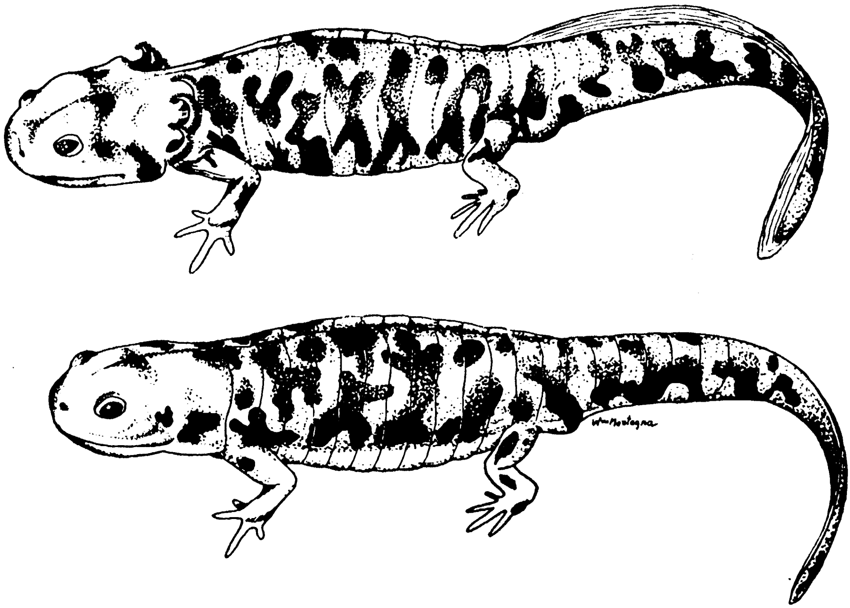


FIG. 189. Effect of change from an aquatic habitat to a land habitat, on *Ambystoma,* an amphibian. Above, the aquatic form. Note the gills and flattened paddle-like tail. Below, the land form. Note the disappearance of the gills and change in the general shape of the animal.

of planarians is changed by the addition of certain chemicals to the water in which they live, animals can be produced having three eyes, or two heads, or no eyes, or even no heads. Other general environmental effects might be described, such as the change in the color of the pelage of the Arctic hare from its white of winter to its brown of summer.

An example of sex differentiation induced by environment is found in the marine worm *Bonellia.* The female worm is much larger than the male and has a rounded body from which extends a relatively long proboscis divided at the end (Fig. 190). The male is a very small animal. Young embryos of *Bonellia* are neither male nor female. If in the course of their wanderings some of these small em-

bryos happen to become attached to the proboscis of the female, they become males. Those not so attached usually develop into females. One of the classic examples is reported by Crew. A Buff Orpington chicken started life as a hen, laid eggs, and was the mother of chicks. Later she began to develop the plumage, combs, and spurs of the male. She crowed and exhibited other male behavior. Later this chicken was mated with some virgin hens and became the father of two normal chicks. An autopsy following the death of this animal showed that the ovary of her hen days had been destroyed by a tumor caused by tuberculosis and that a testis-like organ had developed.

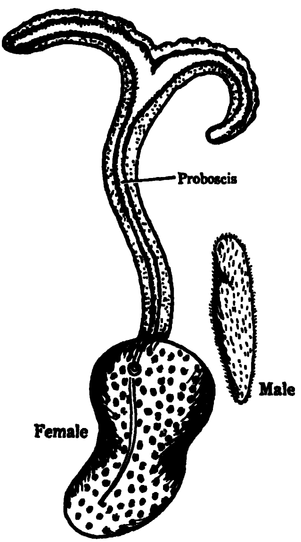


FIG. 190. A marine worm, *Bonellia*. *From Parker and Haswell, "Textbook of Zoology," Vol. I. By permission of the publisher, the Macmillan Co.*

Other instances of environmental effects have already been described, among which are the abnormal animals resulting from a disturbance of normal hormone action. Examples of these already mentioned are the freemartin; cretins resulting from abnormal functioning of the thyroid due to lack of iodine; giants and dwarfs caused by abnormal pituitaries. Such influences as vitamin deficiencies make themselves felt, as in rickets.

From what has just been said, we may gather that, in many cases at least, certain characters of plants and animals are the result of the influence of both the genes and the environment. The genes determine what an organism *may* become, i.e., represent its potentialities or possibilities, but what it *does* become depends also upon its environment. Further discussion of the significance of these facts is reserved until we consider human heredity and eugenics.

IMPROVEMENT OF ANIMALS AND PLANTS THROUGH BREEDING

The art and practice of plant and animal breeding are very old, dating back to the earliest times. As primitive peoples advanced in learning and civilization, man began to train animals to do his work. His growing communities demanded more and better beef and pork, which in turn required more and more fodder, grain, and grasses in all seasons. Communication and warfare demanded beasts of burden

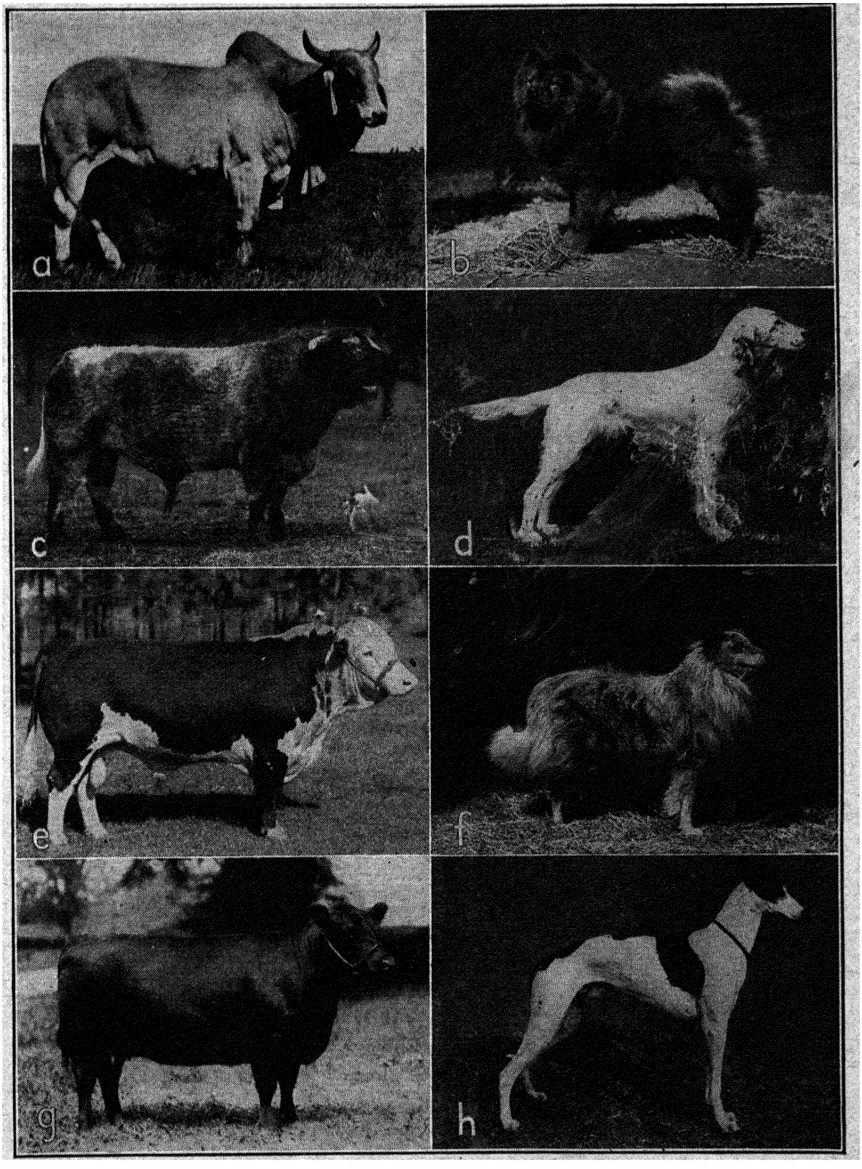


FIG. 191. Various breeds of cattle and dogs. *a*, Brahman bull; *c*, beef shorthorn bull; *e*, polled Hereford bull; *g*, Aberdeen Angus cow; *b*, chow; *d*, English setter; *f*, collie; *h*, greyhound. *Photographs furnished by the Bureau of Animal Industry, U. S. Department of Agriculture.*

and swift couriers. So man began to tame the wild animals, cultivate the grasses and herbs, and in his own primitive way—yet the best he knew—tried to improve what he had. He selected the best of his

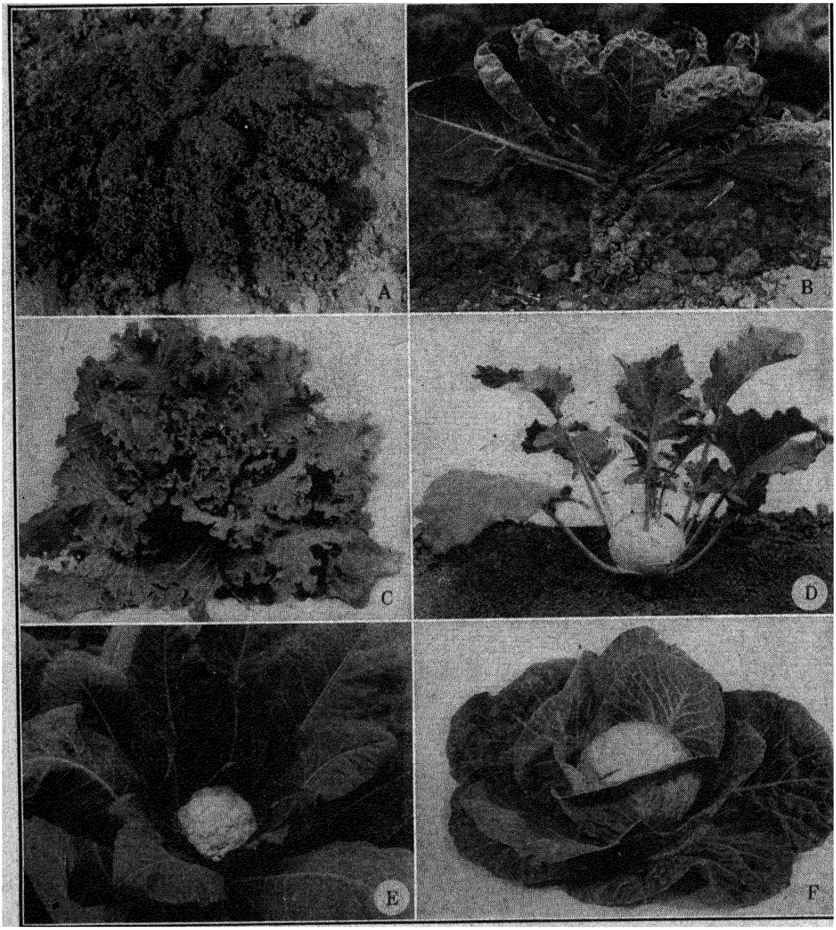


FIG. 192. Plants derived from wild cabbage. *A,* kale; *B,* Brussels sprouts; *C,* kale; *D,* kohlrabi; *E,* cauliflower; *F,* cultivated cabbage. *A, furnished by U. S. Department of Agriculture; B–F, furnished by W. Atlee Burpee Co.*

stock and made crosses. New varieties gradually emerged, but at tremendous cost in time and labor, since, up to 1900, the method used for the most part was a combination of hit or miss, or "trial and error." Today the professional breeder studies his carefully recorded pedigrees and, in the light of his knowledge of genic behavior, works out his matings before he makes them.

Some of our modern breeds of plants and animals have a very interesting history. In Canada the winters are too long and too severe for overwintering wheat plants, and if the wheat planted in the spring matures too late, a grain-rust epidemic may destroy much of the crop. Therefore the farmers require an early-maturing wheat which can be planted in the spring. The scientific geneticist took some early-maturing, good-milling Red Calcutta wheat from India and crossed it with Red Fife, a hardy, upstanding variety. The result of this cross was the Marquis wheat, which is a beardless, red-kerneled, high-yielding wheat resembling the Red Fife in appearance, but possessing the early-maturing, high-yielding qualities of the Red Calcutta.

Our modern dogs are believed to have descended from wolves. By the occurrence and preservation of mutations, cross-breeding, and careful selection, man has developed the different varieties of today. The different types of hogs have been derived from the wild boar, which in the wild state is a savage beast with tough meat and little lard. Domestication and breeding have resulted in the production of "well-bred" hogs weighing as much as a thousand pounds. The wild type "razor-back" of the southern mountains is the domestic variety gone "wild." Goodale, by careful breeding experiments with Rhode Island Red chickens, was able to develop a strain in which the young hens began to lay 55 days earlier than the parents, and in this way he increased winter egg production from 36 to 67 eggs per hen. These and other scientifically controlled breeding experiments have resulted in different types of horses, cattle, pigeons, tobacco, corn, tomatoes, and ornamental flowers, as well as many other varieties of animals and plants (Figs. 191 and 192).

HUMAN HEREDITY AND EUGENICS

We have seen how in various animals and plants some physical and physiological characters are transmitted from parents to offspring. We have pointed out that certain mental characteristics and behavior reactions seem to be associated with the anatomical sexual characteristics of an animal, which are the result of the reactions of certain genes. This would indicate that mental as well as physical traits are inherited. A number of studies have been made of human genetics and its relation to man's biological and social problems. This science, now known as **eugenics** (*eu*—well; *genos*—birth), received a lot of attention from the Greeks; after a lapse of interest through the centuries it was re-established by Sir Francis Galton,

who said that eugenics was the "study of all the agencies under social control which may improve or impair the inborn qualities of future generations of man, either physically or mentally." In other words, it was "the science of being well born."

It is extremely difficult, if not impossible, to carry out actual controlled experimental studies of human heredity. Man is a highly unsatisfactory laboratory animal because of both his high intelligence and his violent likes and dislikes, which prevent his being controlled by the experimenter. Most of the hereditary material and the conclusions regarding the inheritance of various traits have to be drawn from data accumulated from random matings of men and women. Further, there is such a long time between generations and usually so few offspring that it is almost impossible to follow through controlled matings and secure adequate data. In *Drosophila* various lines have been studied through hundreds of generations, for a new generation can appear in a 10- or 12-day period. Weismann, in a comparatively short time, was able to study 22 generations of mice. What data of human heredity we have have come from a study of scattered family histories, from records of public institutions, and from the studies of privately endowed agencies such as the Carnegie Institution of Washington and its Eugenics Record Office at Cold Spring Harbor, Long Island, New York.

Careful study of various human genealogies indicates that many traits are inherited according to the same principles as the traits and characters found in other animals and plants. These characters may be grouped under physical or visible characters; physiological or functional characters; and mental characters. We shall consider some of these traits and, finally, their relation to the social adjustment of the individual.

Some Physical or Visible Heritable Characters

Stature is a trait which seems to be determined by the number of genes for tallness or shortness which may be present in the individual. In crosses between tall and short individuals, shortness seems to be dominant.

Abnormalities of fingers and toes are apparently heritable. Some of these are **polydactyly** (*poly*—many; *daktylos*—finger), where more than five fingers or five toes are present; **brachydactyly** (*brachys*—short), where the fingers and toes are very much shortened owing to the absence of one of the bones in the finger or toe; **syndactyly** (*syn*—with), a condition of webbed fingers or toes, or a

condition in which the thumb and little finger, or the great toe and little toe, are overdeveloped and the other digits are underdeveloped (Fig. 193). This is commonly known as "lobster-claw."

Eye color has been much studied with reference to its inheritance. There are but one or two basic pigments in the iris of the eye. Eye color is determined by the amount and distribution of these color

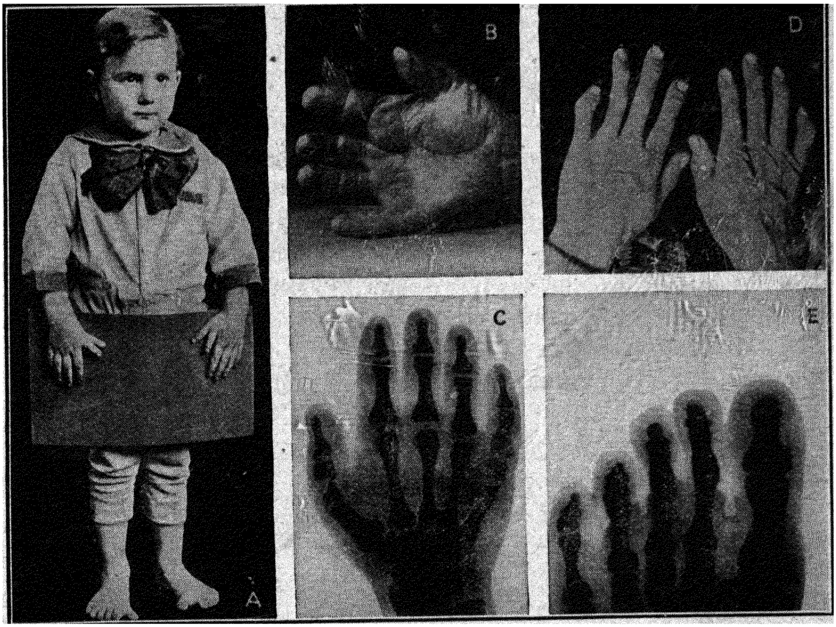


FIG. 193. Heritable abnormalities in man. *A*, polydactyly; *B*, brachydactylous hand; *C*, X-ray of brachydactylous hand; *D*, symphalangy; *E*, zygodactyly. *Photographs furnished by Nathan Fasten. A, D, and E, by permission of the Journal of Heredity; B and C, by permission of the Journal of Genetics.*

granules in the iris. If these pigments are missing the eye appears red or pink, since the blood flowing through the blood vessels is no longer masked by the pigment but becomes visible. In individuals with this defect the hair is white, owing to the lack of pigment. Man and other animals in which these conditions are found are known as **albinos** (*alba*—white).

Texture and color of the skin are hereditary traits. Sometimes the skin becomes dry, thick, and scaly in appearance. This condition, known as **ichthyosis** (*ichthys*—fish), seems to be dominant over normal skin. "Rubber skin," or **cutis laxa,** is a skin defect in which the skin loosens and may be pulled out from the body for a distance.

Attention has already been called to the fact that in crosses between negroes and whites the skin colors appear to be due to cumulative factors. There are more than one hundred abnormal skin conditions that are known to be inherited.

Hair characteristics have been a favorite study not only in man but also in guinea pigs and mice. Studies of hair are concerned with whether it is straight or curly, its color or lack of color, and baldness. Hairs that are round in cross section are usually straight, and wavy hairs are somewhat flattened. Some consider the wavy character to be dominant over straight; others contend that hair type is due to the interaction of a number of genes. **Baldness,** of which there are various degrees, seems usually to be inherited, but it may be caused also by disease. The reason this character is more prevalent in men than in women is that it is dominant in males and recessive in females. It is a sex-limited character. The **color of the hair** is the result of the combinations of two primary pigments, brown and red. Brown pigment is usually dominant over light or yellow. Light blond hair is caused mainly by recessive genes. The various shades of hair may be the result of cumulative factors or of incomplete dominance. We have already called attention to the influence of the lack of pigment in albinos. Premature grayness may be inherited, or it may be attributed to other causes.

Certain characters of the mouth, ears, and nose are apparently hereditary. Some families are afflicted by the loss of certain teeth or even all of them. Cleft palate and hare lip, the result of the failure of certain embryonic jaw processes to fuse, are hereditary. In some families the tongue is held down by the membrane underneath. Odd as it may seem, this abnormality apparently afflicts only the males!

Hereditary Physiological or Functional Defects

Not only are many human structural characters apparently hereditary, but some functional defects are passed along as well. Among the defects of the eyes is **cataract,** which is responsible for more than one-eighth of all blindness. This defect, which centers in the lens of the eye, causing it to become opaque, has various forms. Sometimes it appears to be induced by other causes, such as diabetes, malnutrition, and poisons. We have previously called attention to the hereditary transmission of **color blindness,** which seems to be a sex-linked character. Other eye defects which appear to be hereditary are a certain type of **night blindness** or inability to see in weak light;

myopia or short-sightedness, which behaves as a recessive; **hyperopia** or farsightedness, which seems to be inherited as a dominant. Keenness of vision seems to be inherited also.

About 30 per cent of all cases of deafness seem to be hereditary. Deafness associated with mutism is determined by homozygous recessive genes. Middle-ear deafness **(otosclerosis)** appears at about thirty years of age and becomes worse. This type of deafness is accompanied by "noises in the head." Still another type of deafness which seems to be hereditary is inner ear (labyrinthine) deafness, in which the auditory nerve degenerates.

In the blood and blood vessels one of the best-known hereditary weaknesses is **hemophilia,** or the tendency of the blood to clot too slowly. Naturally any severe wound is likely to result in death. This defect is sex-linked and is lethal in the homozygous condition. The relationship of various blood groups has already been discussed.

Heredity and disease. In the mind of the average person the belief persists that various diseases can be inherited. Indeed, to the casual observer, this often seems to be true. However, careful study has shown that diseases in themselves, with the possible exception of **cancer,** are not inherited, but that certain structural and physiological defects or tendencies are handed down which make the individual peculiarly liable to contract the disease. The almost universal belief among authorities is that, in **tuberculosis,** genes are transmitted for weak lungs, bones, joints with non-resistant protoplasm, making an individual more susceptible to tuberculosis bacilli. The question of the inheritance of cancer is still unsettled. Some individuals and families seem to show a higher percentage of cases than others. Moreover, identical twins often have the same type of cancer in the same organ. Various members of a family may be affected by the same type of growth even in the same organ. However, there is as yet no conclusive evidence of human inheritance of cancer.

Many people are afflicted with maladies such as hay fever, asthmas, and eczema. These are known to the medical profession as **allergic diseases,** which in the opinion of many are hereditary. Here again the disease itself is not inherited but, rather, a sensitiveness to specific substances. For example, the pollen from a certain species of ragweed will send some sensitive individual into a sneezing fit from which he emerges with inflamed eyes, running nose, and a feeling of genuine discomfort. Other substances, more than 200 of them, ranging from pollen of flowers to feathers and horsehair, may cause similar symptoms. The gene for sensitiveness does not manifest itself unless the irritating material is present in the environment.

Heredity and Mentality

Walter points out that plants have no mental or moral traits and that it is a difficult task to discover them in lower animals. On the other hand, it is the presence of mental and moral traits that makes man what he is as a personality. Moreover, scientific study gives some indication that these traits may be subject to the same general laws as physical characters. Suppose that we consider some of the mental characters and reserve the moral characters until later.

What is a mental trait? Usually the expression means some phase of behavior dependent directly upon the type of nervous response an individual makes to various environmental conditions. In the light of modern research we are forced to conclude that so far as mental ability is concerned all men are not "created equal." This conclusion is supported by modern intelligence tests and various statistical studies, particularly those on feeblemindedness. *Who's Who for 1922–1923* listed, according to Hunter and Whitney, only 1 child from 48,000 unskilled laborers and 1 from 1,600 skilled laborers, whereas from the professional classes there was 1 child for every 46 and in the clergy 1 for every 20. Now it is admitted that *Who's Who* is not the only yardstick for measuring mental ability, but it does unquestionably aid in its evaluation.

Feeblemindedness is not insanity but a condition of deficient or dwarfed mental development. For example, a man of forty may have the mind of a child of ten. There are three general classes of these feebleminded individuals: **idiots,** with the mind of a child of two and incapable of caring for themselves; **imbeciles,** with the mental age of a child of six; and **morons,** with the mental age of a normal child of twelve. According to a recent survey, approximately 15 per cent of the population of the United States has an intelligence level of about twelve years of age or under. In a sense, of all these classes, morons are the most dangerous to society for they attain physical and sexual maturity and may even appear normal. Quite often these people are self-supporting and are found in various manual occupations. It is from this group of individuals of low mental, moral, and spiritual stature that the majority of prostitutes, criminals, and paupers come. Practically all authorities believe that most feeblemindedness is the result of a hereditary defect. Contrary to popular belief, Mongolian idiocy is not inherited (Fig. 194).

Insanity is a definite disease or defect of the nervous system and not a condition of general retarded nervous development. Insanity

may appear as a direct result of accident, alcoholism, disease, or some radical environmental change resulting in undue nervous strain. Some one or all of the conditions just mentioned may uncover some hidden hereditary mental sickness. There are no definite conclusions as yet as to the part heredity may play in mental disease, although some evidence exists for the inheritance of certain types. The

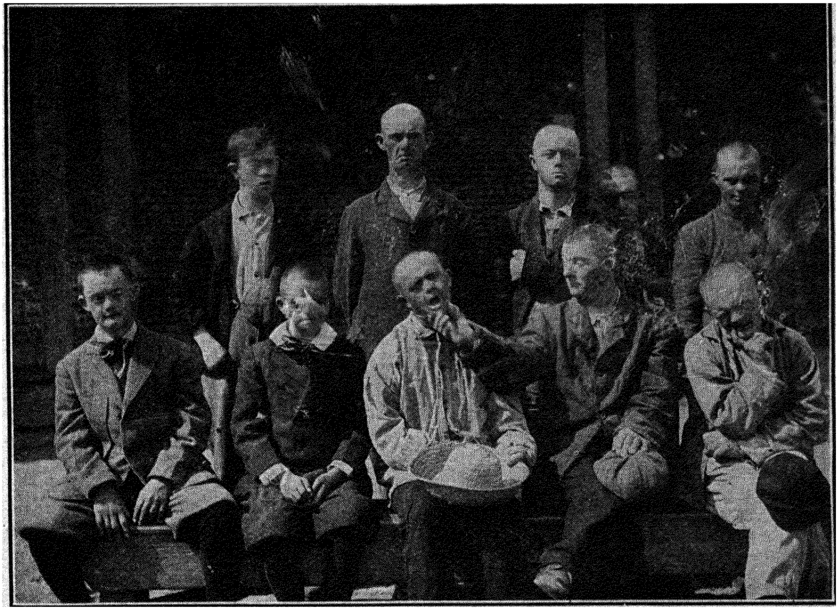


FIG. 194. A group of imbeciles known as Mongols because of their fancied resemblance to members of the Mongolian race. Contrary to popular belief their condition seems to be caused more by the faulty development of the embryo than by heredity. *Photograph furnished by Kate Brousseau, Institute of Family Relations, Los Angeles, California.*

most positive statement that can be made at present is that heredity may contribute a "predisposing tendency or weakness" in the nervous system. Only when a mental defect shows itself in the same way for a number of generations under the same or different conditions and in definite genic ratios can a trait be said positively to be inherited.

Schizophrenia, or sometimes inexactly called **dementia praecox,** results in various types of behavior such as delusions of persecution or grandeur, apathy, carelessness, and lack of interest in the other sex. This mental disorder accounts for about 20 per cent of the patients in mental hospitals. **Manic-depressive** insanity so affects

the individual that he is subject to maniacal phases in which he may commit criminal or violent acts, or to depressive phases during which he may commit suicide. These two types of mental disease appear to be the result of inherited weaknesses and are responsible for about 57 per cent of the inmates of our state mental hospitals. **Huntington's chorea** (*choreia*—dance) comes on about middle life and shows itself in defective speech and general tremors of the body, followed by dementia. This trait behaves as a Mendelian dominant. Traced back in heredity, it is supposed to have come from six persons who came from England to the United States in the seventeenth century. Another form of nervous disease which appears to be hereditary to some extent is **epilepsy,** although it may also be caused by some kind of injury. In a fit of epilepsy the individual loses consciousness, has spasms and convulsions, and often froths at the mouth. The chance of an epileptic parent having an epileptic child is about 1 in 10. Another common nervous disorder, **paresis,** or softening of the brain, is almost always caused by a venereal disease, syphilis. It is not hereditary.

Thus far in our discussion of human heredity, attention has been centered on the inheritance of undesirable traits. Either justly or unjustly, man overlooks the normal or average and is interested in the bizarre and unusual. However, these traits are more easily studied than the usual and commonplace and, attracting attention more readily, have been observed and reported in greater numbers and with more accuracy.

It is a natural corollary that, if undesirable traits are inherited, so also are the desirable ones. Studies made of musicians, literary men, scientists, artists, and others show that the capacities for the various arts run in families. In music we mention the Bach family, where in eight generations, made up of 136 individuals, more than 50 were musicians and composers. In the Darwin family we find a definite capacity for science. Both the father and grandfather of Charles Darwin were physicians, and his sons are among the present-day leaders in science. Additional evidence for the inheritance of desirable traits will appear in the following discussion.

Human Heredity and Modern Social Problems

We have already shown that hereditary characteristics of both animals and plants are carried by the chromosomes in the germplasm, and that inheritance apparently follows definite rules or laws. It has been pointed out that environment plays a real part in the

(Continued on page 354)

Some Hereditary Traits in Man and Their Probable Type of Inheritance

Dominant	Recessive
Skin, Hair, Nails, Teeth	
Black skin (two genes, incomplete dominance)	"White" skin
Dark hair (several genes)	Light hair
Non-red hair	Red hair
Freckles	No freckles
Curly hair (hybrid, wavy)	Straight hair
Woolly hair (negroid type; several genes)	Straight hair
Normal	Hairless (hypotrichosis)
Early baldness (dominant in male)	Normal
Scaly skin (ichthyosis)	Normal
Thickened skin (tylosis)	Normal
Free ear lobes	Adherent ear lobes
Eyes	
Brown	Blue or gray
Hazel or green	Blue or gray
Normal eye	Nearsightedness (myopia)
Farsightedness (hyperopia) (short eyeball)	Normal
Glaucoma (excessive pressure in eyeball)	Normal
Skeleton and Muscles	
Short stature (several genes)	Tall stature
Dwarfism (achondroplasia)	Normal
Extra digits (polydactyly)	Normal
Split hand ("lobster-claw")	Normal
Hare lip and cleft palate (also a recessive?)	Normal
Rupture, susceptibility to	Normal
Circulatory and Respiratory Systems	
Nose bleed and blood cysts (telangiectasis)	Normal
High blood pressure (hypertension)	Normal
Allergy	Normal
Resistance to tuberculosis	Susceptibility to tuberculosis
Cancer	
Cancer of the stomach(?)	Normal
Nervous System	
Normal	Congenital deafness
Auditory nerve atrophy	Normal
Huntington's chorea	Normal
Normal	Amaurotic idiocy
Normal	(?)Schizophrenia
Manic-depressive psychoses(?)	Normal

Special talents (dominance uncertain):

Musical ability.

Ability in drawing, painting, sculpture.

Mathematical ability.

development of plants and animals as seen in such examples as *Bonellia*, the axolotl, corn, and other plants. Apparently the expression of the hereditary potentialities of the germplasm depends upon its surroundings. Evidence has been presented which indicates that man's heredity and development follow the same general principles as those we have seen operating in other animals and plants. With this in mind, let us now consider the possibility of improving man and his civilization by the application of some of the principles of modern heredity—a sociological-biological problem. It must be said here, however, that man in the past and even in the present has paid more attention to the breeding of wheat, pigs, and chickens than he has to the breeding of his own kind. As Carruth puts it, "The only extensive positive impulses to breeding given under civilization have been the breeding of negroes and hybrids for slaves, and the breeding of women for concubines in the Oriental countries, and the subsidizing and breeding of men for cannon fodder in various great imperial countries."

The earlier conceptions of human heredity rested on several lines of fallacious reasoning. For example, it was believed that the blood of our ancestors flowed in our veins. In other words, "blood will tell." Now blood is but one type of somatoplasm, which Weismann showed was not inherited. Accordingly, each individual is "blue-blooded" in his own right, since he made his own blood.

In the next place, in tracing family trees the attention and appraisal given men have not been accorded to women. This may be because woman's place in society is not quite so conspicuous. But from the standpoint of heredity we know that women contribute as many chromosomes to the next generation as men. Further, in reviewing our ancestry it is only human to stress the best and to forget the undesirable.

Now, as we are to make a scientific study of heredity, we must approach the problem with open minds. In the next place, we must consider all the data, that is, all we can find, bearing upon the problem. The true scientist cannot seize upon and exploit only that evidence which supports his own preconceived notions and ignore evidence which seems to point in another direction. The scientist must be on guard not to stress extremes, whether good or bad, and thus to ignore the average. Moreover, all factors which might have bearing on the problem must be considered. Last but not least, accurate measuring devices which tend to eliminate human judgment should be used whenever possible.

Before beginning the study of human heredity we must realize that pure-bred stock is achieved only by close inbreeding, such as the mating of brother and sister, mother and son. Records of such matings must be kept over a number of generations, which for man would amount to several hundred years. But there has been little inbreeding of man, and few accurate records of such matings have been kept. We do not know what is in the germplasm of any particular family or group. The situation has been well summed up by Johannsen in the statement that "from the point of view of a pure-bred dog, we are all curs."

The early classic studies of human heredity such as those of the Jukes and the Kallikaks are interesting not only from a historical standpoint but also because they serve to illustrate a poor scientific approach.

The Jukes family. In the early colonial days there lived in western New York a shiftless, thieving, illiterate backwoodsman named Max Jukes. He married, and a study of his succeeding generations in 1877 showed that of the 540 offspring 310 were paupers who had spent a total of 2,300 years in almshouses. More than one-half of the females were prostitutes. There were 130 criminals, among whom were 7 murderers. Almost all these children were illiterate, although 10 of them had learned a trade—in prison. A further study of this family made about 1915 showed the same general history, although there was some improvement owing to removal from their original environment, bringing an opportunity for better marriages and the dilution of the poor germplasm with that of a higher grade. The validity of the Jukes study has been much in question in recent years. It does not seem to hold up under a scientific mode of attack. It is doubtful that pauperism, prostitution, criminality, morality, and social habits have a hereditary basis. At least thus far, this has not been proved by scientific studies. Moreover, at the time these studies were made, there were no standards to evaluate feeblemindedness. In the next place, not all the descendants of the families were studied. It seems also that no allowance was made for environmental influence. Hogben, a well-known student of heredity, says, "if social biology ever becomes an exact science, the dreary history of the Jukes will be regarded as we now regard alchemy."

The Kallikak family. This study in human breeding has been often used to present more convincing evidence for heredity than that gleaned from the record of Max Jukes. During the stirring times of the Revolution, a well-born young man, fictitiously called Martin Kallikak for purposes of this study, became the father of an

illegitimate son born to a feebleminded girl. This boy grew up to be a wicked degenerate known as "Old Horror"; of 480 of his known descendants, 143 were feebleminded; nor did any of the others show any exceptional ability. Later, Martin Kallikak married a Quaker girl of good stock. From this union there were 496 descendants, none of whom was feebleminded or degenerate. Since the mother of "Old Horror" was feebleminded and apparently immoral, there is reason to doubt that Martin Kallikak could be proved to be the father of "Old Horror," even in any court of law. Furthermore, there is no genic mechanism to account for degeneracy, and according to the records shown apparently no dominant genes were contributed by Martin Kallikak to the child of this first union. Since we know that most undesirable traits crop out when there are two recessives present, Martin Kallikak also must have made his contribution to the worthless side of the house. If this be true, then some of the good Kallikaks of the second marriage must have had hidden in them some undesirable recessives contributed by the father, Martin.

The Edwards family. Richard Edwards, the father of Jonathan Edwards, first married a brilliant but erratic woman named Elizabeth Tuttle. Growing weary of erratic genius, he divorced Elizabeth and later married Mary Talbot. Of the 1,394 descendants studied in 1900, all were eminent citizens. Among them were found doctors, lawyers, clergymen, statesmen, and teachers. It should be noted in passing that the most brilliant members of the Edwards family were descendants of the first union.

Importance of environment. The studies in human heredity just presented are interesting examples of early attempts to study this problem. Unfortunately they had glaring weaknesses and emphasized heredity to the exclusion of environment. Environment undoubtedly plays a part in the development of the individual, but the question is, how much? We know that the presence of factors for feeblemindedness will produce a feebleminded individual no matter what the environment. Desirable genes will express themselves in a good environment but may fail to show their presence in a bad environment.

Perhaps the best studies on the relative effects of heredity and environment on man have come in recent years from certain studies made on groups of fraternal twins and identical twins. Some pairs of these had been reared under the same environmental conditions whereas other pairs were separated from early childhood.

Studies on crime in twins in Germany, published since 1928, showed that both members of a pair of identical twins were more likely to be

criminals than both members of a pair of fraternal twins. Moreover, the type of crimes committed by identical twins resembled each other. However, there was definite evidence that environment played a real part in determining these criminal cases.

Newman and his associates studied 119 pairs of twins, subjecting them to an exhaustive series of modern tests and measurements. This study comprised 50 pairs of identical twins reared together and 19 pairs reared apart, and also 50 pairs of fraternal twins. Some of the conclusions drawn from this study were that identical twins are more alike in intelligence than fraternal twins; identical twins reared apart differed more in intelligence than identical twins brought up together. Differences in prenatal and postnatal environment may be the cause of certain differences. Differences in intelligence, school achievement, and temperament seem to be the result of educational and social differences in the environment. Physical traits are not so readily affected.

Many more instances could be cited of children from defective strains who have been placed in good homes but in whom eventually the hereditary deficiencies appeared. However, the error must not be made of ascribing too much to heredity or too much to environment. One might compare an individual to a piece of steel. The ultimate fate of the steel, if made into a knife, depends upon the stone (environment) on which it is ground and, conversely, what the environment can do in the making of a knife depends upon the inherent qualities (heredity) of the steel.

The Eugenics Problem

The eugenics problem in the light of population trends. As Osborn * points out, "Outside of a wholesale and unparalleled destruction by war, births will determine what races will survive; what language groups will increase; which regions of the world will feel a pressure of population and which will be under-cultivated; which cultural groups will grow and which will decline." This difference in birth rates between the nations and groups of nations causes grave fears for national security and existence.

Suppose that we concern ourselves with our own national problem. It is quite possible that our present population is about optimum size for our country. If so, then our problem from the standpoint of eugenics is not only the maintenance of this present population

* Frederick Osborn, *Preface to Eugenics*, p. 143. Harper and Brothers.

number but the maintenance of an optimum *composition* of our population groups as well.

Let us consider the racial aspects of population trends in the United States. The rate of reproduction among negroes is now greater than that of the whites, and the negroes, Indians, and Mexicans are the groups that present the most serious cultural problems in our country. When we examine the birth rate of the whites with respect to the standard of living, we find that it is highest in the poorest sections of the population. In fact, it is approximately twice as high. This means that the greatest number of children have the poorest environmental opportunities. The following chart is of interest in that it shows the distribution of births according to parental income and educational attainments.

RELATIVE RATIOS OF FERTILITY (FOR ALL WOMEN, AND FOR MARRIED WOMEN ONLY) FOR SPECIFIC SOCIOECONOMIC CLASSES, TO THE CORRESPONDING RATE FOR ALL SOCIOECONOMIC CLASSES, OF RESPECTIVE URBAN WHITE POPULATION INVOLVED *

Socioeconomic Class	*Fertility Rates General*
Annual family income	
$3,000 and over	55
2,000–2,999	73
1,500–1,999	85
1,000–1,499	107
Under $1,000, non-relief	116
on relief	175
Educational attainment	
College	69
High school	95
7th or 8th grade	125
Under 7th grade	146
Total population	100

* Frederick Osborn, *Preface to Eugenics*, p. 127, Harper and Brothers, 1940.

Note that the rate of increase of those on relief is approximately three times the rate of increase of those in the highest income brackets. According to Osborn's studies, in the United States parents whose children make the poorest records on the intelligence tests come from the largest families. Accordingly, we need to develop a national policy which will bring about an optimum distribution of births among the various groups in society, prevent a decline in the present population, and maintain a number and distribution that is optimum for our economic and social system.

Fasten states that the aim of eugenics is to "develop a social consciousness, which will result in the humane treatment and eventual elimination of the hopelessly crippled, diseased and mentally incompetent, and at the same time increase the number of children produced by normal individuals constituting our present civilization." To this end, careful studies must be made of heredity and environmental relationships, and more detailed records of heredity must be compiled and recorded. Campbell divides the human population into three groups:

1. **The best stock** is made up of gifted individuals who are the leaders in society and who control it to a large extent. This group comprises about one-tenth of the population.

2. **The good stock** is comprised of normal, law-abiding, economically independent people. They not only take care of themselves, but also make a worthwhile contribution to civilization. About eight-tenths of the population belongs to this group.

3. **The bad stock or dysgenic group** (*dys*—bad; *genos*—race) furnishes the other one-tenth of the population. Here are found the majority of the feebleminded, insane, prostitutes, paupers, criminals, and the like. These individuals make no contribution to society but, on the contrary, constitute a burden and a menace. Moreover, this is the group that is multiplying most rapidly.

In view of these facts, then, it would seem that the method of attack should be to encourage the first two stocks to increase and, at the same time, to try to eliminate the last group. Such a program must involve extremely careful study of authentic records, careful weighing of **hereditary** and **environmental** influences, and, finally, an evaluation of the characters sought for.

Marriage. According to Davenport, marriage may be viewed from different angles. In a novel it is the climax of courtship; in law it is regarded as two lines of property descent; in society it means the fixing of a certain status; but in eugenics "it is an experiment in breeding." In the light of the last statement and in accordance with the general principles of genetics, only the fit should mate. To encourage desirable mating it has been proposed that all those contemplating marriage must pass a rigid physical and mental test to determine what, if any, undesirable traits they may have which would be transmitted. Such a requirement would involve a careful weighing and balancing because some of our greatest scientific and literary men have been weak physically. Moreover, to determine the mental and physical traits there should be available also a careful compilation of individual genealogies. In the event of failure to

pass the examinations, permission to marry would be given only after certain operations had been performed which would eliminate all possibility of offspring, or certain information had been given concerning the control of reproduction. The advice of William Penn to "marry only for love, but be sure that thou lovest what is lovely" seems to summarize the situation. But the problem is to determine who is to decide "what is lovely."

The fit should not merely be *allowed* to marry but should be *encouraged* to marry and to reproduce as rapidly as possible, certainly at a rate to balance the defective 10 per cent. Some of the encouragements offered in various countries of the world today are: bonuses for children, which will enable the parent to support a large family in comfort; assured incomes for a family based on family size; tax reductions favoring the heads of large families (today most tax reductions are in favor of the defective); the encouragement of bachelors and spinsters to marry by levying heavier taxes on this group, together with employment and housing discrimination favoring the man with a family.

It is interesting to note the steps which Sweden is taking to meet her population problem and declining birth rate. Sweden appointed a population commission made up of representatives from different political parties among whom were expert economists, statisticians, physicians, and biologists. Among other things, this commission recommended that the sale of contraceptives be controlled by the board of health and that more liberal provisions be made in the income tax for parents. It established health centers for mothers and children, set up a scale of payments to cover most of the expenses incident to childbirth, arranged for free school meals, and fostered low-cost housing projects for families.

Segregation and sterilization. The two methods most frequently proposed for the elimination of the undesirable tenth are segregation and sterilization. These are the only ways to get rid of defective genes on a large scale. Marriage too often only covers them up. In the segregation of defectives, the two sexes are separated and placed for life in different institutions where they must be carefully supervised and cared for. Naturally this method requires an annual expenditure of millions of dollars, which we all pay. Moreover, in actual practice, inmates of these institutions often wander off and become the origin of new generations with poor germplasm.

The process of sterilization deprives the individual of his powers of reproduction but leaves his other functions unimpaired. This operation consists of closing, cauterizing, or removing a portion of the sperm duct of the male or of the oviduct of the female. The

result of these operations is to prevent the escape of ova or spermatozoa and thus forestall fertilization. The normal sexual behavior and responses are unimpaired. After any of these operations, the defectives could be released and allowed to marry. In **castration** and **ovariotomy** the entire gonads are removed and the individual sex behavior is much changed. This operation should be performed only in extreme cases.

Some people object to sterilization, claiming that it interferes with the rights and privileges of the individual, is inhumane, and tends to promote sexual promiscuity. The answer to these arguments is that there actually is no interference with the life of the individuals concerned except that they cannot become parents. Furthermore, we must remember that laws in modern society tend to disregard the individual and are based on the principle of the greatest good to the greatest number. In the next place, there is nothing severe, excessively painful, or dangerous about the operation. Moreover, in those states and nations where sterilization laws are in effect and enforced, there has been no noticeable increase in sexual promiscuity. Others contend that there are insufficient data on which to decide the fate of an individual and that society may lose some geniuses by this method. Then there are some who fear the abuse of legalized sterilization by unscrupulous persons.

At the present time more than thirty states and several foreign countries have eugenic sterilization laws. California, Virginia, and Michigan have applied the law with satisfactory results to more individuals than the other states, but it is clear that to be effective the law must be more universally adopted and enforced. It is estimated that sterilization and institutionalization would eliminate one-third to one-tenth of the population of the feebleminded in one generation. The answering argument to those who oppose sterilization is furnished by Justice Holmes' pithy comment that "three generations of imbeciles are enough."

Education. Along with the eugenics program should go a program of education. Everyone should know the fundamental laws of personal mental health, physical health, and hygiene. Instruction in the basic principles and problems of heredity, environmental influences, and sex should be part of the child and adolescent education. Surely it is more desirable that such information be acquired in an orderly, open way from competent instructors than in a surreptitious, unscientific manner from ribald playmates. The physiology of sex is as important as, and is a process as common as, the physiology of digestion.

In the next place in our educational policy we must realize that, although equal opportunity is given to all the children of all the people, these children are not equal in capacity and intelligence. One educational pattern will not fit all. Some of us are naturally equipped to become bricklayers, physicians, or scientists, but environment may influence us to enter some other occupation. Different people have different hereditary molds. Environment or education must recognize the type of mold represented in the individual and polish and finish accordingly. More attention must be paid to the gifted child, for human progress depends to a large extent upon that upper 1 per cent. The job of the eugenist will be only half done if the development of the gifted group is neglected after it is produced. In our present educational scheme we spend more time with the slow and less gifted and fail to realize that the future progress of the race rests with the gifted boy or girl.

Improvement of the environment. It cannot be overemphasized that, in any program of race improvement, it must be recognized that environment does play a part and that the finished product is the result of both heredity and environment. We have already seen that certain genes will produce one kind of an individual under one set of environmental conditions and another type under other conditions. Jennings says that "behavior is bound to be relative to environment. It cannot be dealt with as dependent on genes alone." Consequently, our school curricula should be rich and varied in order to offer a wide variety of choices to match the genic combinations as far as possible. Moreover, physical as well as mental development requires proper housing conditions with plenty of space for fresh air and sunlight with its vitamin-producing ultraviolet. In many progressive communities and states, free medical and psychiatric clinics are being established. There are some who are opposed to these programs, claiming that they tend to increase the number of unfit, which, if nature were allowed to take her course, would vanish from the picture simply by dying. Gradually we are coming to realize that mental sickness may be the result of either environment or heredity.

Immigration. Immigration is a source of good as well as poor germplasm. Immigration laws need to be based not only on the present health and wealth of the individual but also on his past family history. We need to know the I.Q. as well as the pulse rate. It is useless to propose marriage laws based on genealogies for ourselves and at the same time waive these considerations for newcomers. Our immigration laws should be based on the study of the individual rather than of great groups. At the present time there is

a favored swing to the Nordic and Anglo-Saxon. Apparently it is forgotten that we owe our religion to the Near East, our art to Greece and Italy, and our laws to Rome.

Dangers and Difficulties of the Eugenics Program

The measures already suggested for human betterment, such as marriage restrictions, sterilization, and segregation, being kept in mind, what are the possibilities for the elimination of undesirable traits and their genes? Now one can readily recognize individuals who carry dominant undesirable genes. The program here is easy—simply prevent these individuals from breeding. With this program, such traits would almost disappear from the population within a single generation. However, many defects, such as Huntington's chorea and absence of the iris, are comparatively rare. Another type of defective trait which lends itself easily to attack is the sex-linked recessives. These would readily manifest themselves in the males since there is no counteracting dominant. Thus segregation or sterilization of the males would, in one generation, eliminate approximately one-third of the defective genes. However, there would still be certain recessives hidden in "carrier females." The eugenist faces a real task when he attempts to eliminate the simple recessive and multiple recessive genes, and this is the most important group of all. Traits carried by this type of inheritance are very hard to discover except when the individual becomes homozygous for the two recessive characters. If we take feeblemindedness, for example, someone has pointed out that to make any "sizable dent" in the population of the feebleminded it would take a eugenics program of a thousand years, and even after this time there would probably be some undesirable genes which would not be eliminated.

Moreover, many of the difficulties of society come not from individuals clearly recognized as defectives, but rather from those of a borderline group whose members too often become involved in poverty, delinquency, and the perpetration of petty crimes of many kinds. With such individuals it is difficult to evaluate the factor of heredity, for, as we have already seen, environment does play a real part. Bad environment, individual misfortunes, poor education, lack of opportunity—all must be considered. Not only is it difficult to diagnose such cases, but it would be a real task to secure legal and personal consent to sterilize such individuals. From these considerations it can be seen that a perfect society of supermen and

superwomen, through the employment of eugenic measures, is not "just around the corner"!

Separating desirable traits from undesirable. What is to be done with the individuals who have some lesser defects and weaknesses, but who have other highly desirable qualities? If we had been selecting on the basis of physical perfection, the world would not have had Robert Louis Stevenson, Steinmetz, Chopin, or Poe, nor would it have been permissible for this germplasm to be handed down. However, we must not lose sight of the fact that there is reserve germplasm scattered throughout the race from which geniuses emerge and that such genic combinations may occur again. There is little doubt that the professional breeder of other animals and plants would attempt by careful mating to preserve the desirable characteristics and to eliminate the undesirable.

Inbreeding. One of the most effective ways to get rid of defective traits and to establish desirable ones is to inbreed—that is, to mate father with daughter, brother with sister, and the like. The professional plant and animal breeder does this constantly, selecting his desirables and discarding the undesirables until a supervariety of corn, wheat, sheep, or horses is produced. Theoretically this procedure could be carried on with man, but obviously the practical obstacles are insurmountable. In passing, it may be said that inherently there is no objection to marriages between cousins or even between brothers and sisters if there are no hidden recessive defective traits that may appear in a homozygous condition. Perhaps the best examples of human inbreeding studied thus far are found in various European royal families, in some of which there has been a high percentage of desirable traits and in others many undesirable ones.

War. No activity of man is so destructive of good germplasm and such a wrecker of a eugenics program as war. The choice of the mentally and physically fit are marched off to be slaughtered; the rejected unfit are left behind to breed the next generation. One major war can undo countless years of careful planning, repeal the eugenics laws of the statute books, and set back society and civilization half a century or more. In war there is not a survival of the fit; there is the survival of the unfit.

Eugenics and democracy. The ideal eugenics program aims to better the quality of the population and maintain an optimum quantity. It seeks to raise the average level of desirable human variations and at the same time eliminate the undesirable ones, especially low intelligence. The program of eugenics in democracy calls for a selective process which is *natural* and largely *unconscious*, but one in

which the greater number of children will be found in the families which are *most competent irrespective of wealth or social status.* It is very doubtful that democracy can long survive in any nation unless the most competent people in the various social and occupational groups have favored conditions for survival.

SUMMARY

Hereditary characters are carried in the chromosomes by genes and groups of genes, which follow certain rules of behavior and distribution, resulting in the production of types of offspring in definite ratios. Certain characters may be found closely associated, owing either to simple linkage or sex linkage. Some characters may be dominant; others in the presence of certain dominants are recessive.

The new individual is a product not only of his heredity but also of his environment. The environment sometimes brings about the development of a character not already present in the germplasm. Germplasm is potentially immortal and is only protected and nourished by the somatoplasm. Environmental influences usually affect only the somatoplasm and do not reach the germplasm. Theoretically, then, acquired characters cannot be inherited.

The application of genetics to man is known as eugenics. Studies of family histories show that certain desirable and undesirable characters in man are inherited. The eugenics program would try to eliminate defective characters by marriage regulations, segregation, and sterilization, and would encourage more prolific breeding on the part of the fit. However, the task is complicated by hidden defective recessives, unfavorable environmental factors, and, most important of all, the opposition of man to anything which might interfere with his freedom.

CHAPTER XII

HOW ARE PLANTS AND ANIMALS NAMED AND CLASSIFIED? TAXONOMY

Whenever we wish to talk about things, people, or incidents, we must have names by which we may designate them. It is difficult to carry on a conversation about anything for which we have no name, and so we proceed to select or coin a name for the thing in question. In the earliest development of speech there is evidence that names of some kind were applied to all the things that man observed in his surroundings. Thus the plants and animals received names, as did also the streams, the seasons, and the varying climatic conditions that exert such a profound influence on man's comfort. Of course, different tribes and clans in the same and different sections of the country often gave different names to the same plant. Intercommunication among these various groups was lacking or very poorly developed, and consequently there could be no uniform terminology.

Beginnings. Scientists take note of the beginning of science when known facts are first arranged in logical sequence; when knowledge becomes organized, and when such organization makes accurate prediction possible. The first approach to a scientific study of plants and animals was made by Greek scholars, Aristotle and Theophrastus. Not content with the mere naming of organisms, these philosophers attempted to group them according to some scheme of classification. We know from experience that, in dealing with large numbers of different things, some sort of grouping or classification becomes imperative. So these early Greek naturalists, recognizing an ever-increasing number of plants and animals, found it necessary to devise a system of classification. To illustrate the artificiality and looseness of these early schemes of classification, it is only necessary to mention the primary grouping of plants into herbs, shrubs, and trees, and that of animals into air dwellers, water dwellers, and land forms. These beginnings were crude and often based on purely philosophical speculations, but they provided later workers with ideas and a foundation.

The efforts of the early Greeks were followed by eighteen centuries of darkness and stagnation. The first spark of awakening scientific activity appeared in the first half of the sixteenth century. Then came a long line of investigators who devoted themselves assiduously to the task of improving their knowledge of plants and animals, and especially to the development of a system of classification. Apparently the use of plants for food and as sources of drugs was the chief interest that motivated the activities of these workers. Strange as it may seem in this age of specialization, the majority of these early workers were men who had been trained either as doctors or as preachers.

During the sixteenth and seventeenth centuries there appeared a number of volumes devoted to a description of plants and their uses. These herbals, as they were called, in addition to the descriptions and drawings of medicinal and food plants, contained discourses on religious and philosophical subjects. Here were descriptions of strange creatures and even stranger incidents and relationships. Although some of the plants were very well described, and some of the drawings portrayed quite faithfully the features of living plants, many other illustrations and word pictures presented myths created by the lively imagination of superstitious minds.

One of the crude beliefs of this period gave rise to what was styled the "doctrine of signatures." According to this doctrine the Creator had designed certain plant organs in the image of certain organs of the human body, and, wherever such resemblance could be detected, it indicated the remedial virtues of that particular plant in treating diseases of the organ which it resembled. For example, the wrinkled kernels of the walnut were thought to resemble in appearance the surface of the human brain, and therefore they were considered a remedial agent in treating brain diseases.

As the study of plants continued and knowledge increased, the spirit of inquiry grew apace. Confronted by honestly curious minds and keen observation, superstition began to wane. It became more and more apparent that any reliable basis for the grouping of these organisms could be arrived at only through a detailed study of their anatomy. Thus originated the first morphological studies.

Beginnings of modern classification. In the early years of the eighteenth century a Swedish botanist, Carl von Linné, known throughout the scientific world as Linnaeus, developed a new scheme of classification and established a new method of naming plants and animals. In 1735 he published his *Systema Naturae* (Natural System), in which he proposed a classification based on what he con-

sidered natural relationships. Some of the older artificial schemes of classification divided plants into woody and herbaceous plants, and then made subdivisions of these groups based on their medicinal uses. Gerard, an English physician, proposed such classes as trees, shrubs, fruit-bearing plants, rosins, gums, roses, heaths, mosses, mushrooms, and sea plants. The classification devised by Linnaeus was based on the number and position of the stamens and pistils. It was decidedly artificial, but the notable contribution of his work was the new idea and spirit which it introduced and the excellent organization it presented. His publication made Linnaeus famous and marks the dividing line between the old philosophical school that had its origin in ancient Greece and the scientific school of modern times.

Present-day systems of classification. Following the general method developed by Linnaeus, plants and animals are now grouped into certain defined categories. All individuals that have essentially the same structure and life history are included in a grouping or category known as a **species.** For example, all common house cats belong to the same species, and all sugar maples belong to a single species. If a number of different species are found to possess certain fundamental characters in common, they are grouped into a larger category called a **genus.** Thus there is a large number of animals such as lions, tigers, and leopards that have general characteristics like those of the house cat, yet in other specific respects these animals are very different. Because of this general similarity, domestic cats, lions, and tigers, representing three distinct species, all belong to the same genus. Similarly, there are Norway maples and silver maples that have some general characteristics like those of the sugar maple and other specific differences that mark them as separate species. On the basis of their fundamental resemblances, these maples and all others are included in the same genus.

In a similar manner, on the basis of resemblances, like genera are grouped into **families,** families into **orders,** and orders into **classes.** There are but few characteristics that are common to all the members of a certain class. The class to which the cat belongs includes all animals having hair and mammary glands. Therefore, this class (Mammalia) is made up of a heterogeneous assemblage including man, cats, lions, cows, horses, rabbits, and many other animals that have in common hairy skins and mammary glands, as well as a few other less obvious characteristics that determine this particular category (Fig. 195). The class to which the maple belongs is characterized by the presence of two cotyledons in the embryo, and therefore this class (Dicotyledoneae) includes maples, oaks, roses, violets

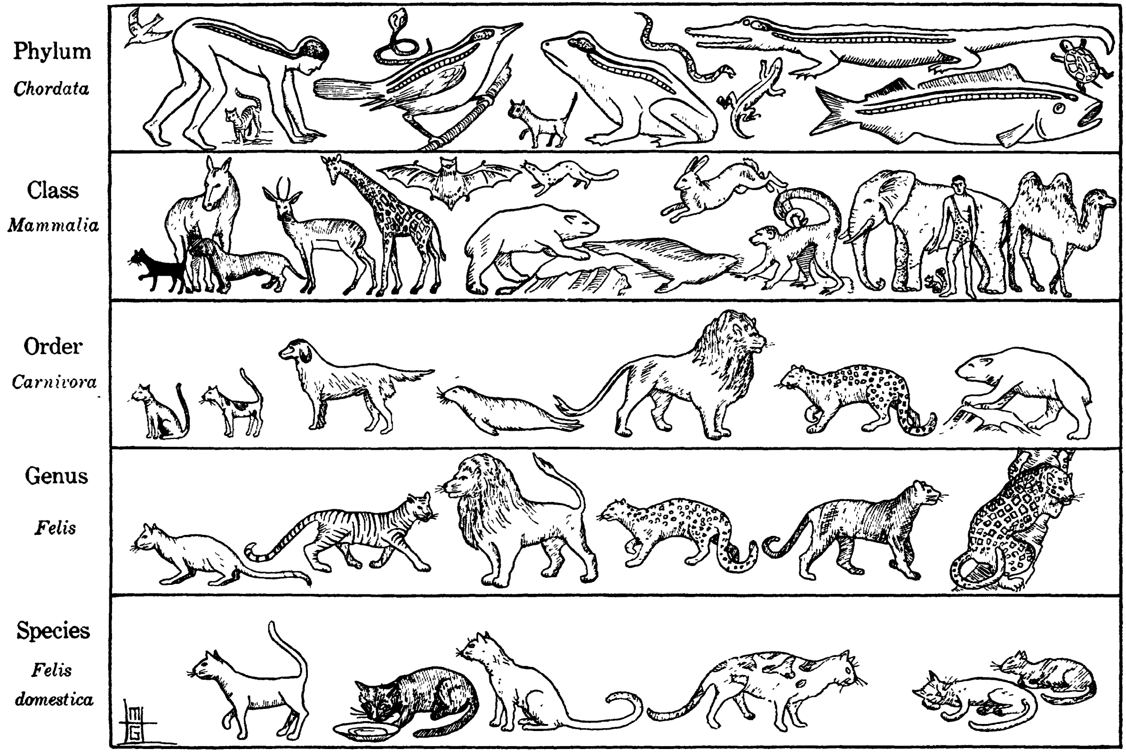


FIG. 195. Diagram showing resemblances and differences in the categories used in the Linnean system of classification. Note that there is an increasing dissimilarity among the animals in passing from species to phylum. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

—in fact, all seed-bearing plants whose embryos have two cotyledons.

Classes are grouped into divisions or **phyla** (*phylon*—race or tribe). Each phylum represents one of the largest divisions of the plant or animal kingdom, for its members need have fewer characteristics in common than those of any of the other categories already mentioned. The presence of a notochord, a dorsal nerve cord, a backbone in most forms, and a few other features characterize the **phylum** (Chordata) to which the cat belongs, and this category includes a large number of very dissimilar animals such as man, fish, frogs, snakes, birds, and elephants, because all of them possess the few characters necessary for membership in this phylum. Seed production is the one main characteristic of the phylum (Spermatophyta) to which the maples, oaks, roses, and violets belong. This one characteristic permits the inclusion in this phylum of all seed-bearing plants such as grasses and lilies whose embryos have but one cotyledon; peas and beans with two cotyledons; and pines with several cotyledons. In fact, all the seed-bearing plants belong to this phylum.

Any or all of these categories may be subdivided into smaller groupings designated by such terms as **subkingdom, subphylum, suborder, subfamily,** and **subgenus.** Linnaeus thought that a species was a fixed, immutable category, but today we know that intergrades occur and that some species are extremely variable. Consequently, categories, called **varieties,** may be formed as subdivisions of the species. This method of grouping may be illustrated by the classification of the common cat and the sugar maple:

- Kingdom—Animalia
  - Subkingdom—Metazoa
    - Phylum—Chordata
      - Subphylum—Vertebrata
        - Class—Mammalia
          - Order—Carnivora
            - Family—Felidae
              - Genus—*Felis*
                - Species—*domestica*

- Kingdom—Plantae
  - Subkingdom—Metaphyta
    - Phylum—Spermatophyta
      - Subphylum—Angiospermae
        - Class—Dicotyledoneae
          - Order—Sapindales
            - Family—Aceraceae
              - Genus—*Acer*
                - Species—*saccharum*

SCIENTIFIC NAMES

The concepts of genera and species existed before the time of Linnaeus, but no one had consistently used generic and specific names to designate organisms. Linnaeus adopted this usage and emphasized it by constant application in all his work. Its convenience

was recognized at once, and it became the universally accepted method of naming plants and animals. The name of the genus plus the name of the species forms the scientific name of the organism, and the system is therefore known as the **binomial system** (*bi*—two; *nomen*—name). The person who first publishes the name of a genus or species is considered the author of that group, and his name or its abbreviation is placed after the name of the group. Thus we see that the scientific name of the common house cat is *Felis domestica* Schreber; that of the sugar maple, *Acer saccharum* Marsh.

The necessity for some such system of nomenclature becomes quite obvious when one recalls that common names are almost as variable as the people who use them. An organism that is tagged by a certain common name in one locality is given an entirely different name in another locality. Thus the common bird *Colaptes auratus*, known quite generally as the flicker, may be called high hole, yellow hammer, golden-winged woodpecker, clape, wakeup, or 120 other names in as many different localities. The common pasture mullein (*Verbascum thapsus*) has been designated in different places at various times by more than 140 different common names, such as woolens, Aaron's rod, and flannel plant. From these illustrations and numerous others that could be cited, we may conclude that common names applied to plants and animals are merely nicknames, and like nicknames they have only a very restricted local value. The only genuine, widely recognized name is the scientific name established in the system of binomial nomenclature. It can readily be understood how such a system eliminates much of the confusion resulting from the use of common names by providing worldwide uniformity in the naming of organisms.

In the time of Linnaeus, Latin was the accepted scholarly language throughout Europe, and all important documents and scientific articles appeared in this language. Thus the first scientific names were Latin names. These early names have been preserved, and the use of Latin in naming plants and animals has been universally accepted —quite fortunately, because the Latin language, being no longer spoken, is not subject to variation. It is a fixed (dead) language, and the Latin scientific names are thus destined to remain unmodified throughout the years. Likewise, in the time of Linnaeus, Latin was also the universal language of scholars, and consequently scientists everywhere were more likely to use the same name for any given organism. Thus still greater uniformity was given to binomial nomenclature.

Returning to our previous illustrations, we see that the scientific name of the cat, *Felis domestica* Schreb., is the name known to scientists everywhere. In all the countries of the world scientists recognize *Verbascum thapsus* L. by that name, regardless of whether it is called mullein in America, woolens in England, or Aaron's rod elsewhere. Thus we see that the system of binomial nomenclature and the use of the Latin language as a medium of expressing the names have been extremely important in the development of our knowledge of plants and animals. Aristotle is supposed to have known about 520 species of animals; Theophrastus knew practically the same number of species of plants. Consequently, the naming and classification of these organisms presented a much simpler problem than that which confronts the taxonomic biologists of today, who have recorded approximately 335,000 species of plants and more than 800,000 species of animals—a total of more than a million names.

The scheme of classification developed by Linnaeus has been replaced by others, but the general method he introduced is now used by all systematists throughout the world. As our knowledge of animal and plant relationships has increased, the work of classification has been improved and a closer approach has been made to the ultimate goal—a natural system of classification. As contrasted with an artificial system of classification based on superficial resemblances, a natural system is one based on relationships determined by inheritance or, in other words, "blood relationship." International congresses of botanists and zoologists convene from time to time to formulate rules of taxonomic procedure, and thus the greatest possible uniformity in scientific nomenclature is sought.

WHAT IS A SPECIES?

Just as the classification proposed by Linnaeus has been changed, so also has the concept of species been modified. Linnaeus considered each species "a thought of God," an immutable group created by the Almighty and remaining constant through all time. According to this interpretation, a lion was created as such, could never be modified in any way, and therefore would always remain a lion. This, of course, would be equally true of man, dog, horse, rose, potato, apple, and every other organism. A species once created might become extinct, but it would never change, and therefore it could give rise to no new species. This concept was known as "Special Creation." We now know that such rigid categories do not exist.

Today a species is generally interpreted as a mere taxonomic concept **(Linnaean concept)** for a group of individuals of the same kind. The individuals comprising a species are thought to be very closely related by descent (ancestry), as indicated by their resemblances. This modern Linnaean concept of species, as we have seen, does not coincide precisely with his original definition of a species. Some workers have proposed establishing the species on the basis of specific reactions of the protoplasm, and this is known as the physiological concept of species. However, all the schemes of classification now in general use employ the modified Linnaean species-concept.

Geneticists generally consider a species as a natural group whose characteristic features are determined by the genes and genic combinations. Usually, plants and animals of one species cannot be crossed with those of another, and, where such crosses can be made successfully, the resultant hybrids are almost or completely sterile. Interspecific and hybrid sterility are regarded as agencies that help to keep species clearly delimited as natural groups.

LINNAEUS

Since Linnaeus has such an important place in biology, a brief story of his life may prove interesting. He was born at Stenbrohult, Sweden, in 1707. His father, a poor country preacher, determined that his first son should also be a preacher, and therefore sent him to Wexiö to study Latin and Hebrew. However, the lad found these subjects painfully dull and made very little progress. The school authorities advised his father to take him home, but a Dr. Rothmann, who had detected in the work of Linnaeus an unusual ability in natural science, urged the father to permit his boy to enter the study of medicine. In fact, Rothmann was so keenly interested in young Linnaeus that he took him into his own home and gave him free private instruction for a whole year. This proved to be the turning point in the lad's life. The kindly doctor had unwittingly paved the way for the development of one of the most famous men in the field of biology.

The following year, at the age of twenty, Linnaeus was a student at Lund, where he lived with Dr. Stobaeus, professor of medicine. The doctor had a choice library to which no one was admitted except his assistant. But Linnaeus was so eager for knowledge that he persuaded the assistant to get books for him on condition that they would be returned to the shelves early in the morning. Linnaeus spent most of the night reading, and the scheme worked very satisfactorily until the doctor, attracted by the light, went to the room of Linnaeus at two o'clock in the morning and saw him poring over one of the prized books of the library. The doctor was so pleased by the zeal of the student that he gave him a key to the library and urged him to read during the day so that he might rest at night.

After a year at Lund, Dr. Rothmann advised Linnaeus to go to the university at Upsala. His parents consented to the change but were too poor to give him

any financial aid. At the end of one year his funds were exhausted, and he was so poor that he was compelled to line his shoes with pasteboard to keep his feet from coming in contact with the snow and frozen ground. Despite such hardships, he pursued his studies vigorously. One day in the botanical garden, Celsius, the dean of the university, chanced to hear him describing some plants. He marveled at his knowledge of plants and was so pleased with him that he took him into his own family. Throughout his student days and his life afterward, Linnaeus always manifested a marked capacity to excite the admiration

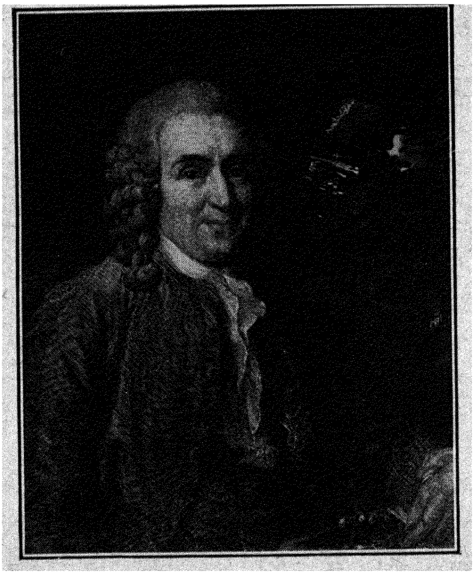


FIG. 196. Linnaeus (Carl von Linné) 1707–1778, the founder of modern taxonomy. *From Holman and Robbins, "Textbook of General Botany." By permission of W. W. Robbins and of the publisher, John Wiley & Sons.*

and sympathy of those who had similar interests. Celsius secured for Linnaeus an appointment to a private docentship which gave him the right to deliver lectures for fees. His lectures proved so popular that he began to draw students from the regular classes in the department. This success aroused the jealousy of the regular professors, who then obtained the adoption of a rule that made it impossible for any undergraduate to deliver public lectures.

About this time Linnaeus received a grant from the Academy of Sciences at Upsala to make an exploratory journey into Lapland. He left Upsala in the middle of May and returned the following autumn, having traveled some 2,500 miles, mostly on foot and alone. He brought back a large collection of plants, among which was the little twinflower—*Linnaea borealis*—his favorite flower, and the only plant that bears his name.

Linnaeus now felt that his further advancement would depend on his obtaining the degree of doctor of medicine. Since no school in Sweden offered such a degree, he decided to go to Holland. With the financial support of his future father-in-law, he made the journey and within a few weeks was granted the

doctor's degree at a small university. Shortly afterward, in Leyden, he met the famous physician and botanist Boerhaave, who had the reputation of keeping Peter the Great of Russia waiting in the vestibule for two hours before admitting him. Linnaeus knocked at his door every day for a week without success. Finally he sent one of his published books to Boerhaave, and the old aristocrat was so delighted with it that he consented to see the author at once. He took Linnaeus into his yard to see a tree which he thought had never been described, but the young man recognized it immediately and even named the book wherein it had been described.

In 1735 Linnaeus published his *Systema Naturae,* which he had begun in Sweden. This brought fame, and there followed a three-year period of almost feverish publication, one work appearing after another with incredible rapidity. He had now become an authority in the field of botany, and, after visiting the chief botanical centers and the principal botanists of England, France, and Germany, he returned to Sweden.

For a time Linnaeus practiced medicine in Stockholm, but in 1741 he was made professor of botany at Upsala, the position for which he had so long been preparing himself. He could now devote his entire time to biological science and to the direction and encouragement of all those interested in this work. He immediately became the foremost member of the university, and a period of the most intense activity followed. He taught classes during both winter and summer, published much scientific work, reorganized the botanical garden and made it one of the finest in Europe, and all the time carried on an extensive correspondence. Throughout the world he was accepted as an authority on questions of natural science and was consulted by both governments and private individuals. He was held in highest esteem both at home and abroad, and finally was inducted into the nobility, receiving the name von Linné.

The decade 1750–1760 was the climactic period of his life and achievement. During this period he produced the last of his best publications and was granted his greatest honors. The remaining years of his life represent a period of failing health and steadily declining activity. The poverty of his youth entailed real hardships, and these, coupled with the burdens and responsibilities of his later years, had sapped his strength. In his fifties he began to experience serious illness, and, although he continued to work more or less effectively, his momentous drive was gone and his movements were impaired. During the last ten years of his life he suffered repeated paralytic strokes, which finally resulted in practically complete paralysis. His great intellectual powers faded until they were effectually dimmed. In 1778, death came to him, at the age of 71 years, and ended a career that had recharted the progress of biology.

CHAPTER XIII

THE ANIMAL KINGDOM. WHAT ARE INVERTEBRATES?

We have already learned that all living organisms are made up of protoplasm and products of protoplasm which differ somewhat in different organisms. Not only does the protoplasm of the plant differ from that of the animal, but the protoplasm of each species of animal and plant differs in some way from that of all other species. Though these differences may be slight, they are sufficient to cause the development of thousands of varied forms. However, no matter what form protoplasm may assume, it possesses those fundamental characteristics such as organization, metabolism, irritability, growth, and reproduction which we have already studied. When we attempt a survey of the animal kingdom, we find creatures of all sizes and shapes, presenting strange variations and devices responsible for carrying out the fundamental life processes. These living things which are grouped into the animal and plant kingdoms, as we have already seen, are further subdivided into smaller groups based on fundamental resemblances. We are now going to present a "bird's-eye" view of various animals and show something of their modes of life, relationships, and the role they play in the general economic and social interests of man.

PHYLUM PROTOZOA

(*protos*—first; *zoon*—animal)

Protozoa are generally microscopic animals which for the most part live in either fresh or salt water although some live in the soil and others, as "uninvited guests," in the blood, body cavity, and intestines of other animals, including man. Protozoa exist either as single cells or as groups of cells called colonies. In colonies, for the most part, each cell is like every other cell, although some colonial groups have a certain amount of differentiation or specialization of cells that perform specific functions. No tissues or organs are present in Protozoa. The animals belonging to this phylum are sepa-

rated into various groups according to certain fundamental resemblances.

Class Sarcodina (*sarx*—flesh), or the amebalike protozoa. Protozoa of this group have peculiar organs of locomotion called **pseudopodia** (*pseudo*—false; *podos*—foot). By studying the ameba, a member of this group, we shall acquire some understanding of the nature of sarcodinians in general. Amebas may be found on the

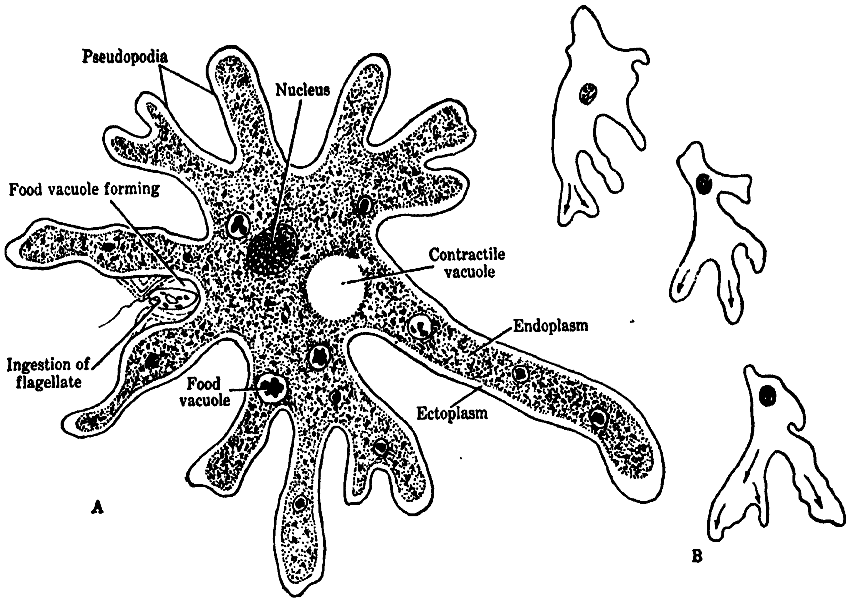


FIG. 197. Ameba. *A,* structural details. *B,* manner of locomotion. The flow of protoplasm is indicated by arrows.

surface of the mud in ponds and ditches and on water plants. If we examine some scrapings of mud or plants under the microscope, we may see irregular-shaped masses of protoplasm—amebas—flowing over them. Here and there projections of protoplasm push out from the animal, and the animal moves. These projections are pseudopodia. If we examine the ameba more closely (Fig. 197), we find that the extreme outer zone of the body, the **ectoplasm,** is fairly transparent and free from the granules found in the inner zone, which is darker in color and very granular. The inner zone is the **endoplasm.** If we stain the ameba, it is possible to see the nucleus lying in the endoplasm. Scattered through the endoplasm are vesicles containing fluid and particles of food. These are **food vacuoles.** If in its wanderings the ameba encounters a bit of food, it "swallows" it

by the simple process of flowing around and over it, and later completely surrounding it with protoplasm. The food is digested and absorbed into the surrounding protoplasm. The solid waste is eliminated at any place by the animal's flowing away from it. As Causey puts it, "There never was a principle of hygienic science or of table manners it [ameba] hasn't violated successfully."

Metabolism of course goes on in this bit of protoplasm. Oxygen diffuses into, and carbon dioxide diffuses out of, the protoplasm throughout its entire surface. As we look more closely at the endoplasm, we may see a small, transparent vesicle appear and then disappear by apparently squeezing together. Later it may reappear. This is the **contractile vacuole,** which helps regulate the amount of water in the ameba.

The ameba has **irritability.** It moves toward some substances and engulfs them; it avoids other substances by flowing away from them. When shocked by electricity or subjected to vibrations, it pulls in the pseudopodia and contracts into a sphere.

Reproduction takes place by fission. Under unfavorable conditions, such as the drying up or freezing of the surrounding water, it may secrete a resistant membrane around itself, forming a **cyst,** and in this quiescent state await the return of better living conditions.

All the Sarcodina are unicellular and have pseudopodia, but some are not so simple as amebas. The pseudopodia of certain forms are blunt; others are fine, radiating, and raylike. Certain of these animals cover their naked protoplasm by secreting shells of silica or calcium carbonate (Fig. 198). In fact, many of the layers of limestone and chalk rock are made up of countless billions of these little shells of sarcodinians that lived millions of years ago. The pyramids of Egypt are built of limestone made from these shells.

Aside from rock formation, we have little good to say of these animals. *Endamoeba gingivalis* has been erroneously blamed with assisting in pyorrhea. This ameba is spread by kissing. A relative, *Endamoeba histolytica,* enters the digestive tract from filth on poorly washed lettuce, celery, and the like, or in polluted water. It reaches the large intestine and there feeds on the intestinal wall and red blood cells, making ulcers and causing bleeding and amebic dysentery. Some may get into the liver and cause liver abscesses.

Class Flagellata (*flagellum*—little whip). These little animals are called flagellates because they usually move by pulling themselves along by the lashings of one or more long whiplike strands of protoplasm called **flagella.** Their bodies, though pliable, are rather definite in shape with a well-defined anterior end.

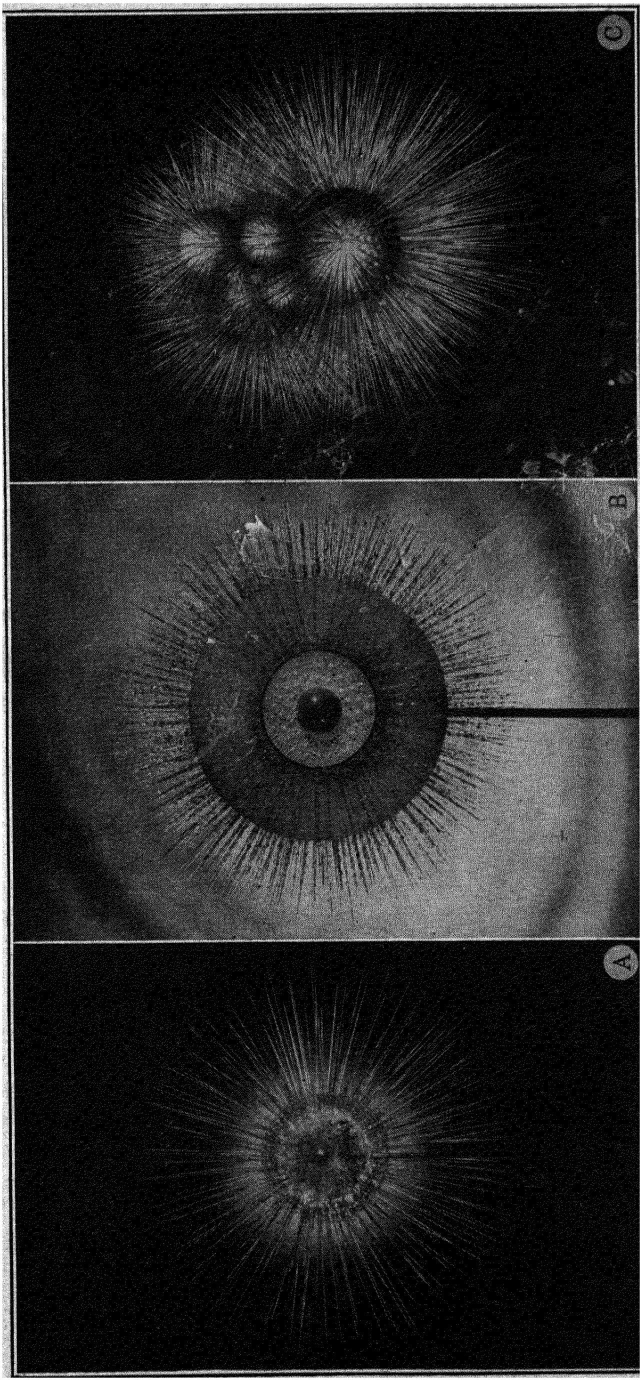


FIG. 198. Other members of class Sarcodina. *A*, *Aulonia*; *B*, *Actissa*; *C*, *Globigerina*. *Photographs of glass models furnished by the American Museum of Natural History.*

Like amebas, these animals are single-celled, have food vacuoles, and many have pseudopodia (Fig. 199). In some flagellates the food is engulfed in ameba fashion. In some, the food is absorbed

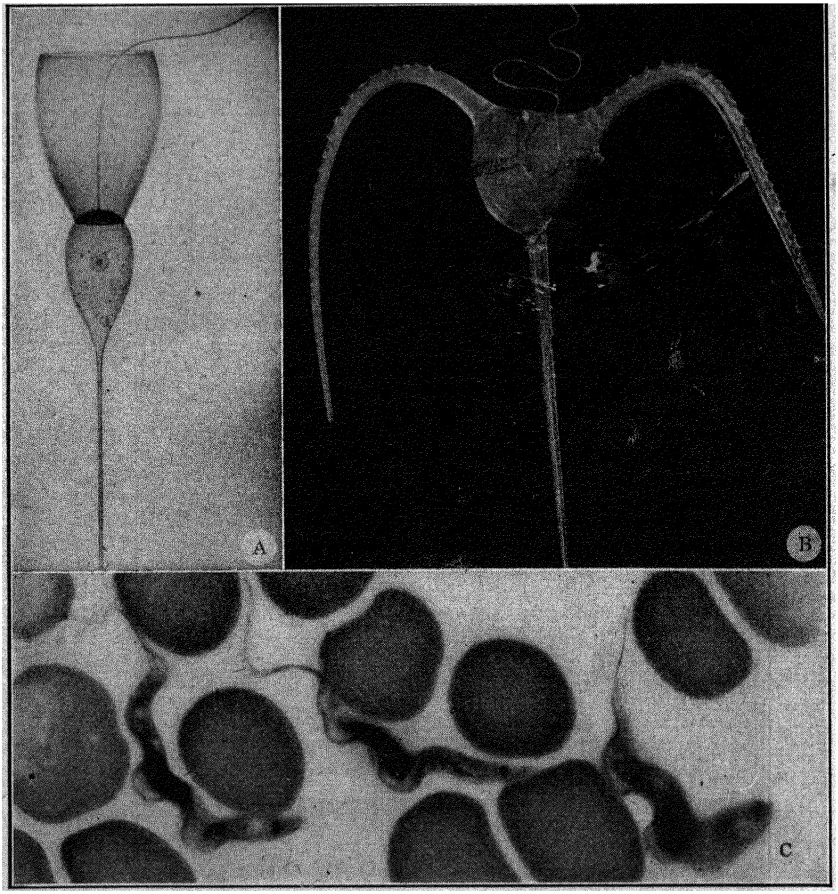


FIG. 199. Other members of class Flagellata. *A, Monosiga; B, Ceratium; C, Trypanosoma. A and B photographs of glass models furnished by the American Museum of Natural History. C, photomicrograph furnished by General Biological Supply House.*

through the entire body surface; in others, the food enters through a definite spot to which it is drawn by currents set up in the water by the lashing flagella. Many of these forms resemble green plants in that they have chloroplasts and manufacture their own food. In fact, many botanists lay claim to these organisms because, in addition to having chloroplasts, many of them form spores after the

fashion of plants. Some biologists believe that the Flagellata are more primitive than amebas because of their plant characteristics and because some flagellates have a somewhat ameboid body to which is attached a flagellum.

Some flagellates form colonies with certain of the cells specialized for reproduction and others for feeding and locomotion. However, differentiation has not proceeded far enough to form tissues or many-celled animals, **Metazoa.**

The Flagellata contribute their share of plagues to man. Some live in reservoirs and give man's drinking water a most surprising taste and "audible odor." There are also a number of parasitic forms. One of them, *Giardia,* seen under the microscope looks like the face of an owl. *Giardia* lives in the upper bowel and may cause nervousness on the part of the host.

Two groups of flagellates are especially important, the *Leishmania* type and the trypanosome type (Fig. 199). They live in the blood and other tissues and are the cause of a number of serious diseases. The *Leishmania* parasites may become localized in either the viscera or the skin.

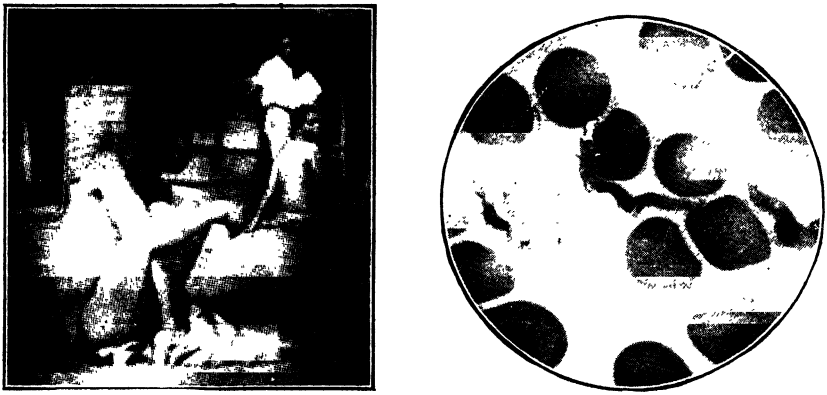
Leishmania diseases. Kala-azar or "black sickness" is found in India, North China, around the Mediterranean, and in Sudan and has been known to depopulate entire villages. Apparently the disease is transmitted by the bite of the sandfly. The parasites occur in the blood and are especially abundant in the spleen, liver, bone marrow, and lymphatic system. The white corpuscles of the body become gorged with these apparently indigestible flagellates. Destruction and avoidance of sandflies may be one way to prevent the disease.

Oriental sore occurs quite frequently in the eastern Mediterranean region and southwestern Asia. Sandflies may be the transmitting agents, and it is certain that the disease can be transmitted by contact with an infected individual. Oriental sore is a shallow ulcer which may persist for several months to a year or more. One attack gives immunity.

Espundia occurs from Mexico and Central America to northern Argentina. Extensive sores appear on the ears, face, forearms, and legs and become eroded and secondarily infected. Often the disease attacks the nasal cavities, the mouth, and pharynx. It is quite possible that the disease is transmitted by sandflies.

Trypanosome diseases. Sleeping sickness is a trypanosome disease of equatorial Africa (Fig. 200). These parasites are carried by a tsetse fly which has probably become infected from sucking the

blood of some other intermediate host. When the fly bites a person it loses some of the protozoans in the saliva. The trypanosomes get into the blood stream, where they multiply. After several weeks or months, the person bitten becomes feverish, loses flesh, and lacks "pep." Eventually the parasites infect the cerebrospinal fluid, and then the victim passes into a slumber from which he usually never awakes. Thus far no certain cure has been discovered for sleeping sickness.



A B

FIG. 200. *A*, African sleeping sickness: advanced stage. *B*, trypanosomes, causing sleeping sickness. *A, reproduced from Culbertson "Medical Parasitology" by permission of Columbia University Press. B, photomicrograph furnished by the General Biological Supply House.*

Chagas' disease is caused by a trypanosome parasite apparently carried by a large, blood-sucking bug (*Triatoma megista*) which lives in the mud or thatched native houses. The disease is contracted when the feces of the infected bug are rubbed into the tissues of man. The disease, found in Brazil, Argentina, Venezuela, and Uruguay, is more common among infants and young children. Severe infections may result in death.

Besides trypanosomes found in man, others have been found in horses, camels, cattle, pigs, dogs, monkeys, and armadillos.

Class Sporozoa (*sporos*—spore; *zoon*—animal). All the species of this group are parasitic not only on animals of other phyla but even on other Protozoa. They have no means of locomotion, and they lack contractile vacuoles. As the name of the class indicates, one of the characteristics of these animals is the tendency to form spores at some time during the life cycle. In the formation of spores

the nucleus of a "parent" animal may divide a number of times. Each nucleus appropriates some cytoplasm, and the parent breaks up into a number of small sporozoa each with a nucleus and some cytoplasm.

Perhaps we can get a better picture of a typical animal of this group if we study a malarial parasite, *Plasmodium*. When a female mosquito (*Anopheles*) bites a person, there may be injected into the blood stream some saliva containing *Plasmodium* in the form of

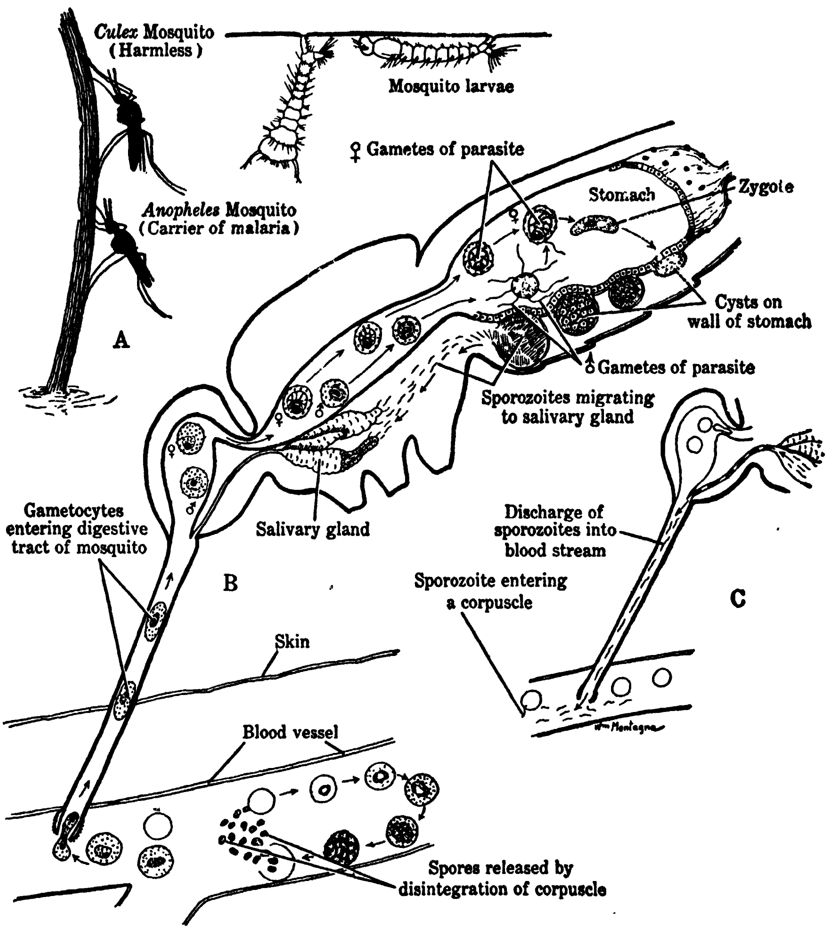


FIG. 201. Life history of the malarial parasite, *Plasmodium*. *A*, diagram showing position of mosquitoes when biting. *B*, diagram of mosquito sucking blood, and incidentally the malarial parasites from a man infected with malaria. *C*, same mosquito piercing the blood vessel of an uninfected man and injecting the malarial organisms. *Adapted from various sources.*

sporozoites (Fig. 201). The sporozoites enter the red blood corpuscles, grow, and break up into young spores **(trophozoites).** After a certain period the corpuscle bursts, releasing many new parasites and much waste material into the blood stream, causing a chill. The young spores enter new corpuscles and multiply. So the cycle continues unless quinine, plasmochin, or atabrine is administered to kill the parasites when they escape from the corpuscles. Sometimes the chills come every third day and sometimes only every fourth day, depending upon the life cycle of the particular species of *Plasmodium.*

Quite often these malarial parasites form sex cells, or **gametocytes.** When the gametocytes reach the stomach of a female mosquito, the female gametocytes are fertilized by spermatozoa (from male gametocytes), and the resulting zygotes then develop into wormlike forms **(oökinetes).** These burrow through the stomach walls and encyst themselves. Asexual reproduction follows within the cyst, forming many slender sporozoites, the stage infective to man. The sporozoites later migrate to the salivary glands of the mosquito where they remain until she—for it is the female mosquito—bites another victim and the vicious circle is started again. Study carefully the diagrammatic sketch of the life history in Fig. 201. It is estimated that malaria is responsible directly or indirectly for one-half of the annual deaths of human beings of the world exclusive of war and accident. There are more than a million cases of malaria per year in the United States.

Parasitic Sporozoa are found in other animals and in man; however, many of them are comparatively harmless. Some forms may cause the death of rabbits and chickens. Others cause Texas cattle fever and diarrhea in cattle. Still others are responsible for a chronic disease in silkworms known as **pebrine.** Birds may have bird malaria but often show no ill effects. Many Protozoa have an even more complicated life history than the malarial parasite.

Class Ciliata (*cilium*—eyelash). The body is covered with an outer, rather tough transparent **pellicle** through which protrude small **cilia,** used in locomotion. In many of these Ciliata the number of cilia may be very restricted and other structures called **cirri** may be present to assist in movement. Another characteristic is the presence of two kinds of nuclei in the cell. There is usually a large nucleus which controls the vegetative processes of the cell and one or more smaller nuclei which are responsible for the hereditary characters. Although no tissues or organs are present, many animals of this group are very complex. The protoplasm in various regions of

the cell is highly modified, and structures known as **organelles** (little organs) may be present (Fig. 202). Ciliata are widely distributed in fresh and salt water, and a few live as parasites in man and other animals. A better idea of this group can be obtained by studying the structure and behavior of *Paramecium.*

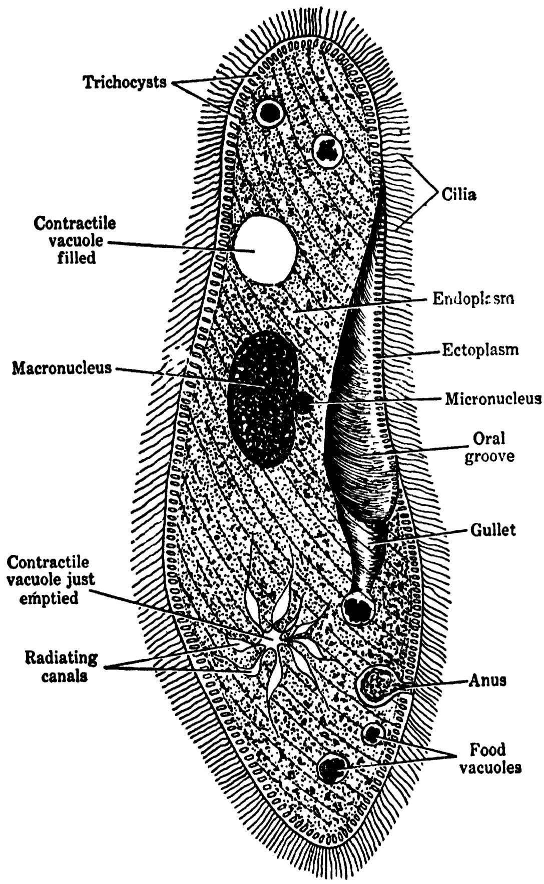


FIG. 202. Structure of *Paramecium. After various authors.*

Paramecium is found in most stagnant pools. It is shaped somewhat like the sole of a slipper and is covered with numerous cilia which propel the animal through the water. Leading from the anterior end of the animal is a furrow known as the **oral groove** which leads down into the animal as the **gullet.** The cilia along this groove are somewhat longer and create a current of water flowing down into the gullet and bringing in such food as bacteria and protozoans.

As in amebas, these ingested food particles lie within food vacuoles. As they circulate through the protoplasm the food is digested and assimilated. Oxygen and carbon dioxide are exchanged through the general body surface, and two **contractile vacuoles** eliminate excess water (Fig. 202).

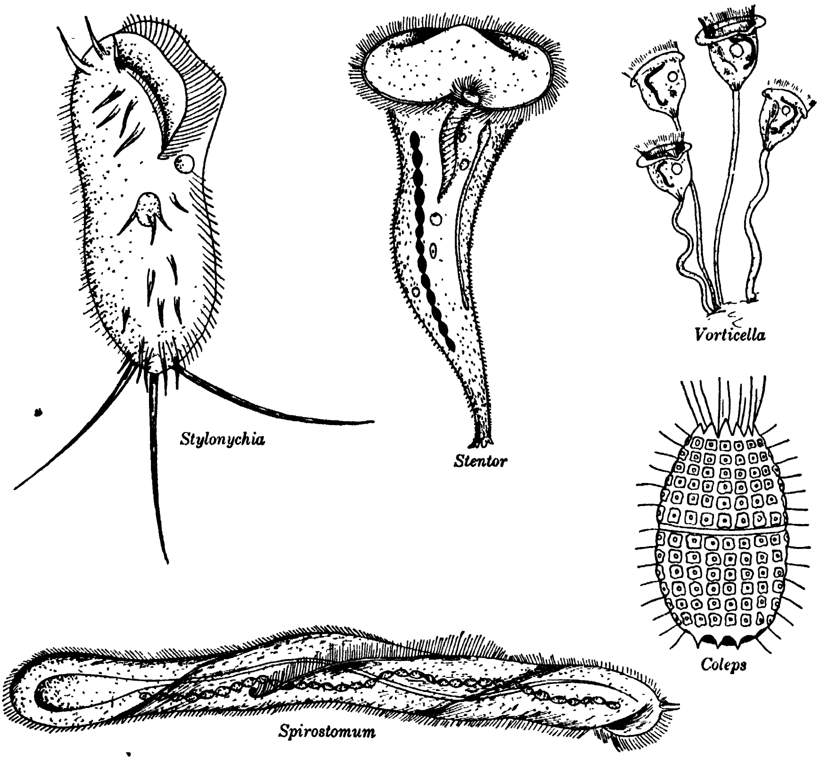


FIG. 203. Various members of the class Ciliata. *Modified from various sources.*

Under the pellicle is a region containing protective structures called **trichocysts** (*thrix*—hair). When the animal is attacked by other protozoans, as it often is, the trichocysts shoot out and form around the body a jellylike network which may keep the enemy at bay. One of the enemies, another protozoan called *Didinium nasutum,* can eat animals ten times its own size and one or two hours after such a meal it is ready for another.

Paramecium reproduces asexually by transverse fission. Sometimes two individuals may unite and exchange nuclear material, a process called **conjugation.** A somewhat similar process of nuclear reorganization called **endomixis** may take place in a single indi-

vidual. Conjugation and endomixis seem to impart new health and vigor to the animals.

Several of the Ciliata are reported to be parasitic in man, but the most troublesome one is *Balantidium coli,* a rather large form visible to the naked eye. It is normally parasitic in the digestive tract of hogs, from which in an encysted condition it escapes with the feces. Man introduces it into his digestive tract by eating improperly washed food Normally this parasite seems perfectly content to swim around in the large intestine devouring fecal matter, but sometimes it attacks the intestinal wall, causing ulcers. Dysentery follows, and frequently death results. Proper sanitation for both hogs and man is the best way to prevent the disease.

PHYLUM PORIFERA

(*poros*—channel; *ferre*—to bear)

The Porifera or sponges live mostly in salt water, although a few forms are found in fresh water. The phyllum is well named, for the animals are literally full of channels or **canals** which open to the outside through **pores.** Portions of the canals are lined with cells which resemble the flagellates. Each of these cells has a flagellum surrounded by a **collar.** These cells make up the **gastric epithelium.** The beating of the flagella brings the food and oxygen-laden water into the sponge through certain pores and canals and expels it through others which are larger and more centrally located. The larger central canals or cavities **(spongocoels)** open to the outside by a large opening called the **osculum** (little mouth) (Fig. 204). The food, consisting of microscopic animals and plants, is engulfed by the cells of the gastric epithelium and digested as in the Protozoa. Sponges have no circulatory system and food is transferred by ameboid wandering cells as well as by diffusion since every cell has one exposed surface. Excretion and the exchange of oxygen and carbon dioxide take place through the surface of the cell in the same way as in Protozoa. Solid wastes may be eliminated by wandering ameboid cells which carry them to the outside.

Sponges reproduce asexually by budding and also in some species by the formation of **gemmules** (little buds). A gemmule is a group of cells enclosed within a resistant coat which enables it to live through unfavorable conditions. Sponges may reproduce sexually also. The zygote develops into a free-swimming larva which, after swimming for a time, settles down and develops into an adult ani-

mal. We have already noted the remarkable powers of regeneration possessed by sponges.

The mention of flagellated and ameboid cells brings to mind at once the Protozoa, and, indeed, sponges are not far removed from

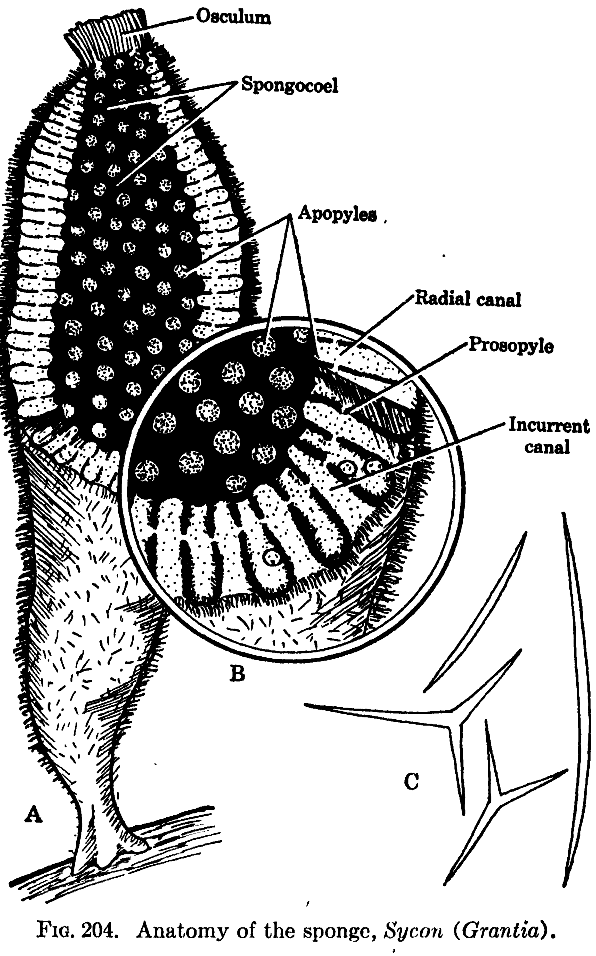


FIG. 204. Anatomy of the sponge, *Sycon* (*Grantia*).

this phylum. However, in sponges we find specializations not present in the Protozoa. The gastral and dermal epithelia are **tissues.** Between the two layers is a rather indefinite jellylike layer in which are found cells that furnish the skeletal structure of the sponge. In most sponges the supporting skeleton is made up of finely branched needlelike structures called **spicules.** In some sponges they are made of calcium carbonate; in others they may be finely spun needles and

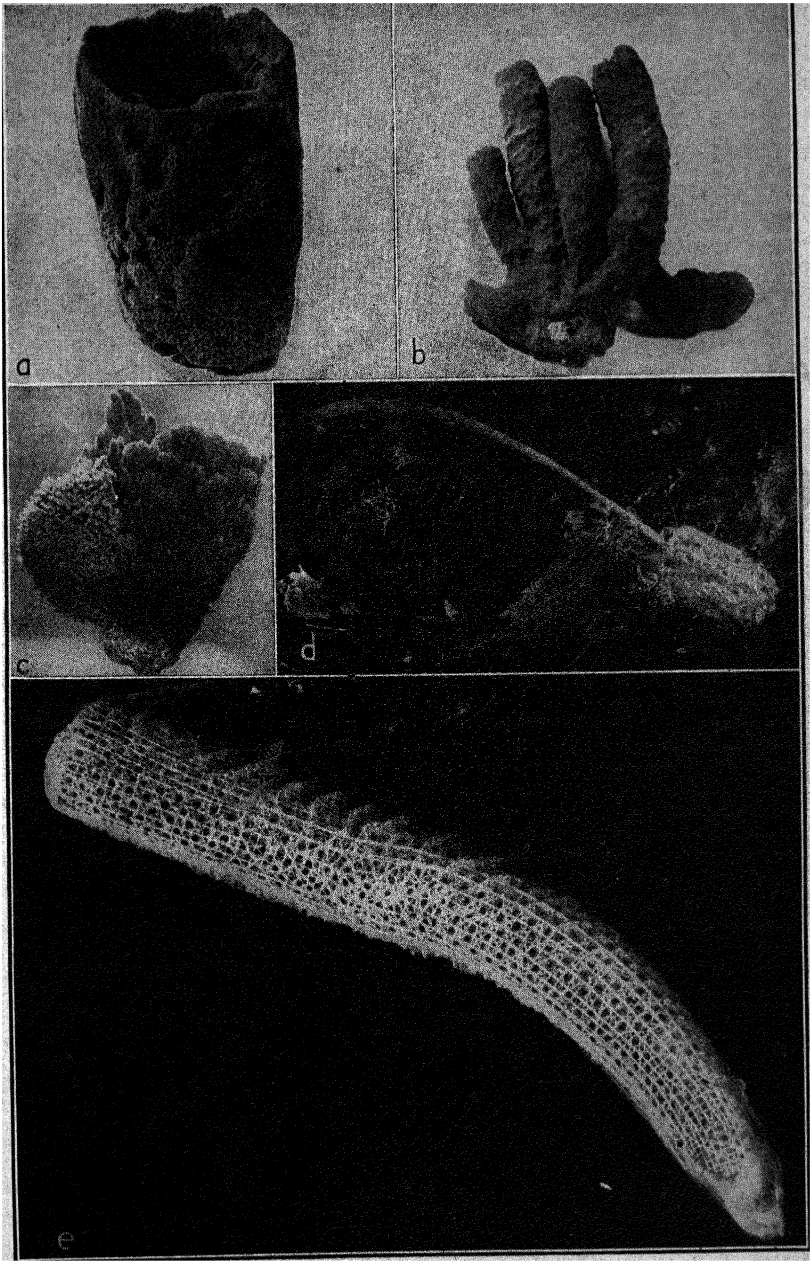


PLATE II. Types of sponges. *a,* bath sponge; *b,* finger sponge; *c* (*left*), grass sponge, (*right*) sheep's wool sponge; *d,* glass rope sponge; *e,* Venus' flower basket. Sponges *d* and *e* have skeletons of "spun glass." *Photographs a, b, d, and e furnished by Erwin S. Koval; c, by Fish and Wildlife Service, U. S. Department of the Interior.*

threads of glassy silica. The spicules not only support but also protect the sponge, for they offer no encouragement to the buccal cavities of would-be diners. Some sponges are supported by a skeleton of a more flexible, tough substance called **spongin.**

Although sponges do have tissues, no organs are present. In addition to the dermal and gastral epithelia already mentioned, we may

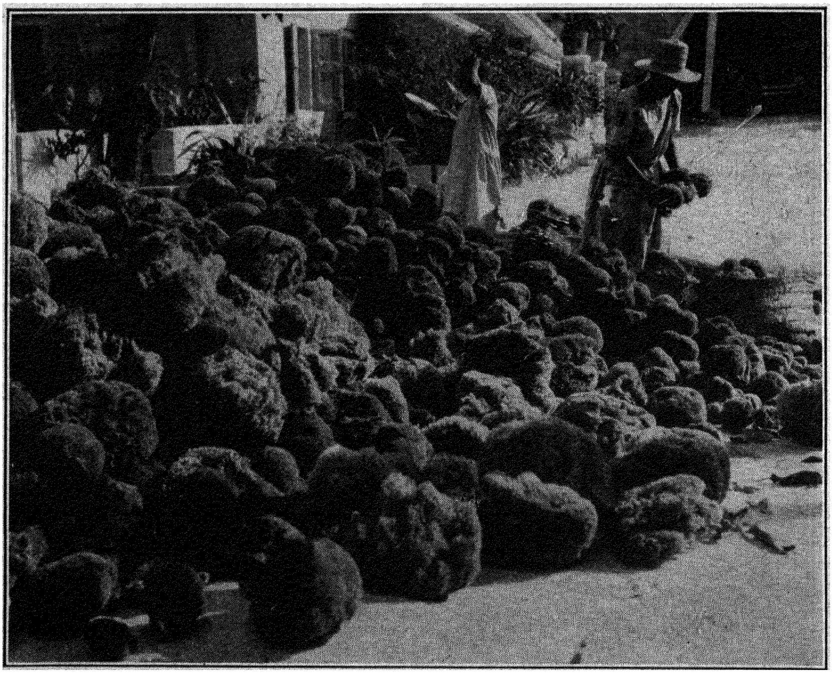


FIG. 205. A sponge market in the Bahama Islands. *Photograph by Ewing Galloway, New York.*

mention the skeletal-producing cells found in the jellylike layer. Contractile fibrils have developed in the cells which surround the pores, but there is no nervous tissue. The pore cells are both motor and sensory in function and therefore constitute a neuromuscular mechanism.

As indicated above, the Porifera are doubtless related to the Protozoa. Although they are too complex to be classified with that phylum, they show no fundamental similarities with animals higher in the evolutionary scale. They are considered members of that great group of many-celled animals, the Metazoa. Someone has pointed out that sponges apparently went up an evolutionary blind alley in the animal kingdom and remained merely sponges.

The value of the total yield of the sponge fisheries of the world amounts to more than $3,000,000 each year (Fig. 205). The bath sponge of commerce has a skeleton of spongin, and it is this skeleton which we use.

In preparing bath sponges, the animals are torn from their moorings usually by divers who bring them to the surface and place them on the deck of a vessel where they are allowed to die and rot. Then the decayed and softened flesh is washed and squeezed from the skeletons, which are carefully sorted and prepared for the market. Sponges are propagated commercially by "planting slips" attached to stakes fastened to a frame which is lowered to the ocean bottom. This frame is raised after a year or so and the sponge crop is harvested.

PHYLUM COELENTERATA

(*koilos*—hollow; *enteron*)

The Coelenterata are aquatic animals, most of which are found in salt water. In this phylum are jellyfishes, sea anemones, corals, and the fresh-water hydra. The Coelenterata are sometimes spoken of as "modified gastrulas" since the bodies of the animals are made up of only two well-defined cell layers, an outer **ectoderm** and an inner **endoderm.** Between the layers is a jellylike layer or **mesoglea** which has no definite cellular structure. The endoderm lines the digestive cavity, called the **gastrovascular cavity,** which is really a primitive enteron. These animals are **radially symmetrical;** i.e., they can be divided into three or more fairly similar parts or segments. Animals such as the earthworm, grasshopper, and chicken, which can be divided into two equal similar parts only by one plane passing through the long axis of the body, are said to be **bilaterally symmetrical.** Tentacles are usually present, and the animals are equipped with stinging cells called **nematocysts** (*nema*—thread; *cyst*). Many of the coelenterates have an **alternation of generations (metagenesis)** in their life history, a phenomenon that will presently be explained.

Class Hydrozoa (*hydra*—water serpent; *zoon*). One of the simplest of the Coelenterata is the fresh-water *Hydra* (Fig. 206). *Hydra* is a sessile, somewhat tubular animal about one-fourth to one-half of an inch in length. It has a double wall made up of an outer **ectoderm** and an inner **endoderm** between which is the **mesoglea.** The endoderm surrounds the central digestive or **gastrovascular cavity.** The **mouth,** surrounded by an elevated liplike structure, the **hypostome,** is both the entrance and exit of the gastrovascular cavity. Surrounding the hypostome and mouth is a circlet of **tentacles** equipped with batteries of stinging cells called nematocysts. The animal thus described is often called a **polyp.**

A hydra extends its tentacles into the surrounding water as long flexible lines. When some animal, such as a tiny aquatic worm or the water flea *Daphnia,* happens to swim by, it comes in contact with one or more of these fishing lines and also with the "trigger hairs" of the nematocysts, causing them to explode. In this reaction, they

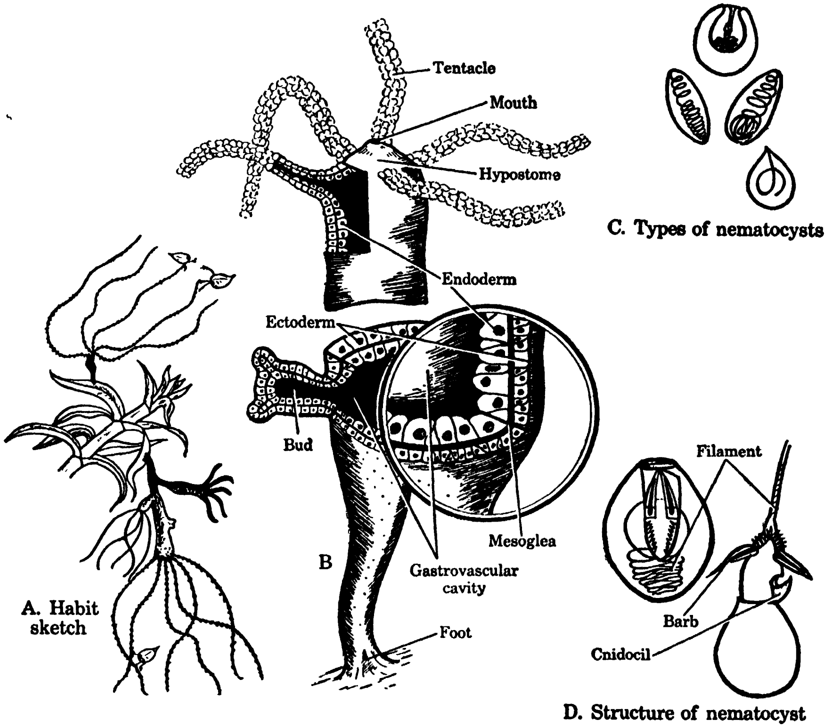


FIG. 206. Anatomy of hydra. *C, after Hyman in Trans. Amer. Microscopical Soc., Vol. L. D, redrawn from Borradaile and Potts, "Invertebrata," by permission of the publisher, the Macmillan Co.*

shoot out small strands, some of which may wrap around parts of the prey while others, tipped with poison, penetrate the victim and paralyze it. Then the tentacles contract, and the struggling prey is drawn to the mouth and moved on into the digestive cavity. Here it is partly digested into smaller food particles which are moved about and distributed by the lashings of the flagella found on some of the endoderm cells. The particles are then engulfed by pseudopodial processes of the endoderm cells, in which digestion is completed. Indigestible portions, such as the hard shells of some animals, are later

ejected through the mouth, for there is no anal opening in *Hydra* or other coelenterates. Food is distributed by diffusion to other body cells. The oxygen-carbon dioxide problem is solved in the same way as in Porifera and Protozoa, by direct interchange between cells and environment.

The adjustment mechanism is better developed in *Hydra* and the Coelenterata than in Protozoa and Porifera. Contractile fibrils are

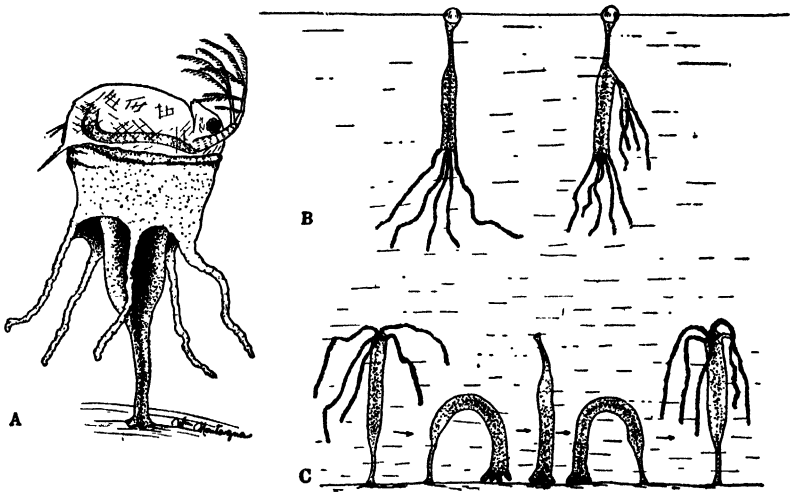


Fig. 207. *A,* hydra disgorging a daphnid too large to be ingested (swallowed); *B,* hydra floating attached to a gas bubble; *C,* the "walking" of a hydra by alternate attachments of base and apical regions.

located in the basal regions of the ectoderm and endoderm cells, but no true muscle tissue is present. Since certain ectoderm cells are both sensory and motor they are called **neuromuscular cells.** Nerve cells are arranged in the form of a **nerve net,** as has been pointed out elsewhere. In a sense, this may be considered a very primitive nervous tissue.

Hydra can move from place to place by turning cartwheels—that is, by attaching its tentacles and releasing its foot or base, which then bends over and becomes attached in a new place. It may move by the creeping of its foot. Sometimes cells located in the foot form a bubble of gas, and, attached to this "balloon," the animal rises and floats around on the surface, suspended mouth downward in the water. *Hydra* is very sensitive; when stimulated by touch, jarring, chemicals, and other stimuli, it will contract both tentacles and body (Fig. 207).

Hydra reproduces asexually by budding and sexually by eggs and sperms produced in ovaries and testes respectively. *Hydra* also possesses powers of regeneration almost equal to those of sponges.

***Obelia* and alternation of generations.** *Obelia* is a colonial salt-water hydroid. It resembles a tiny bushy plant and grows attached

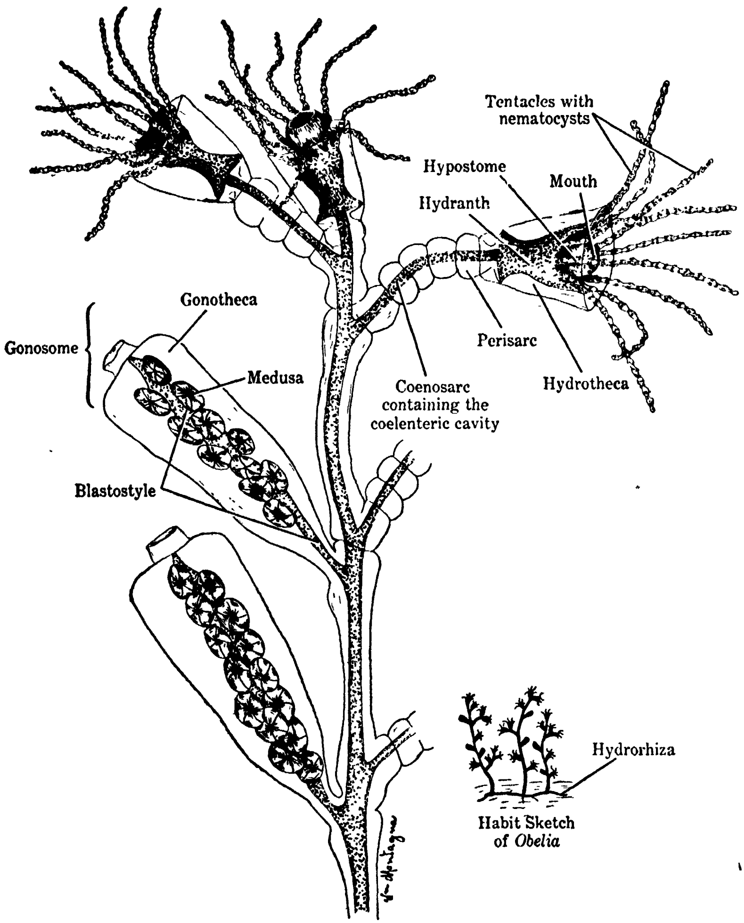


FIG. 208. *Obelia,* a colonial coelenterate.

to wharves, piling, or seaweed (Fig. 208). The bushy animal bears a number of little polyps called **hydranths,** which resemble little hydras except that they are all connected by a common **gastrovascular cavity** whose walls make up the **coenosarc.** Thus, when some members of the colony eat, all eat—a really communistic set-up. In

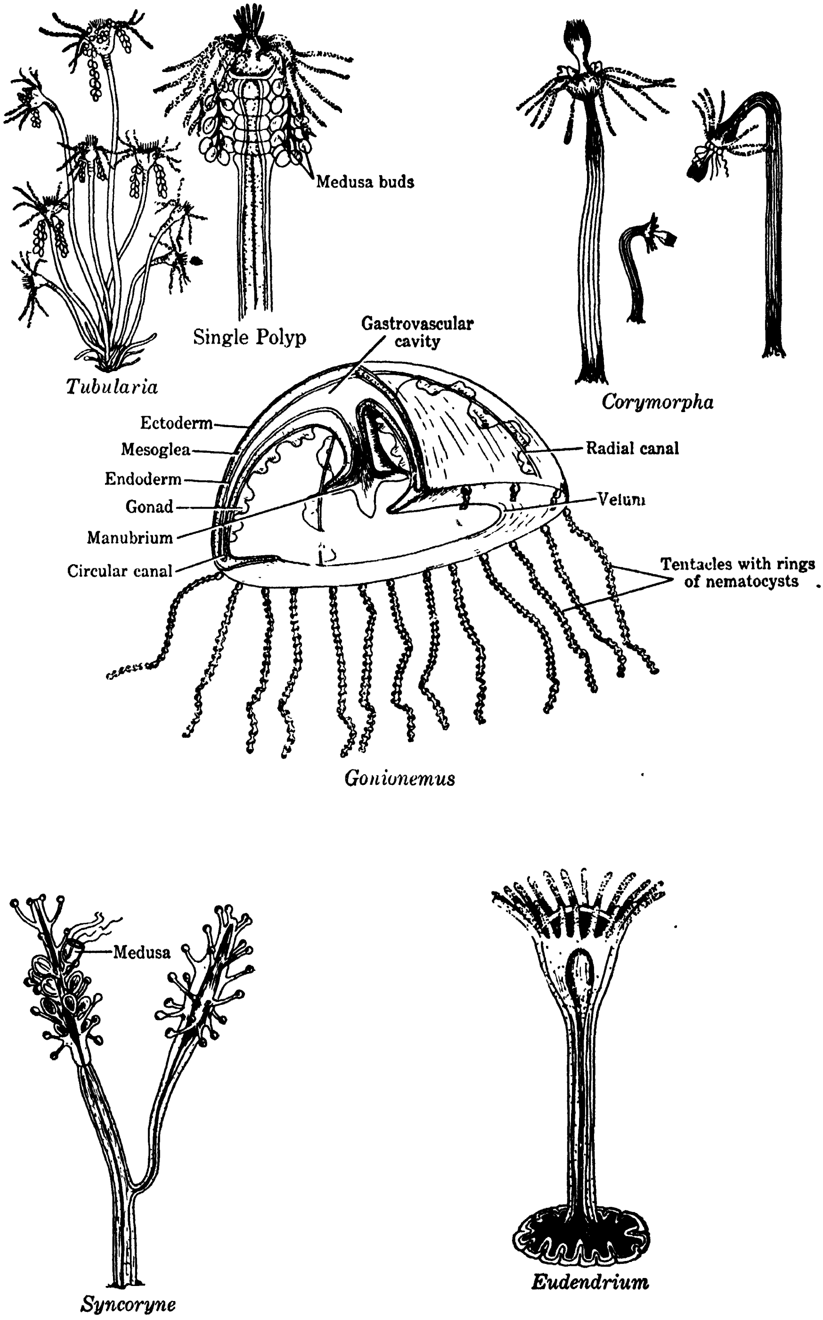


FIG. 209. *Gonionemus,* and other Hydrozoa. *Modified from various sources.*

Obelia the hydranths and stalk are protected by a chitinous or horny sheath.

In addition to the nutritive polyps or hydranths, reproductive polyps, called **gonangia,** are present. The differentiation of members

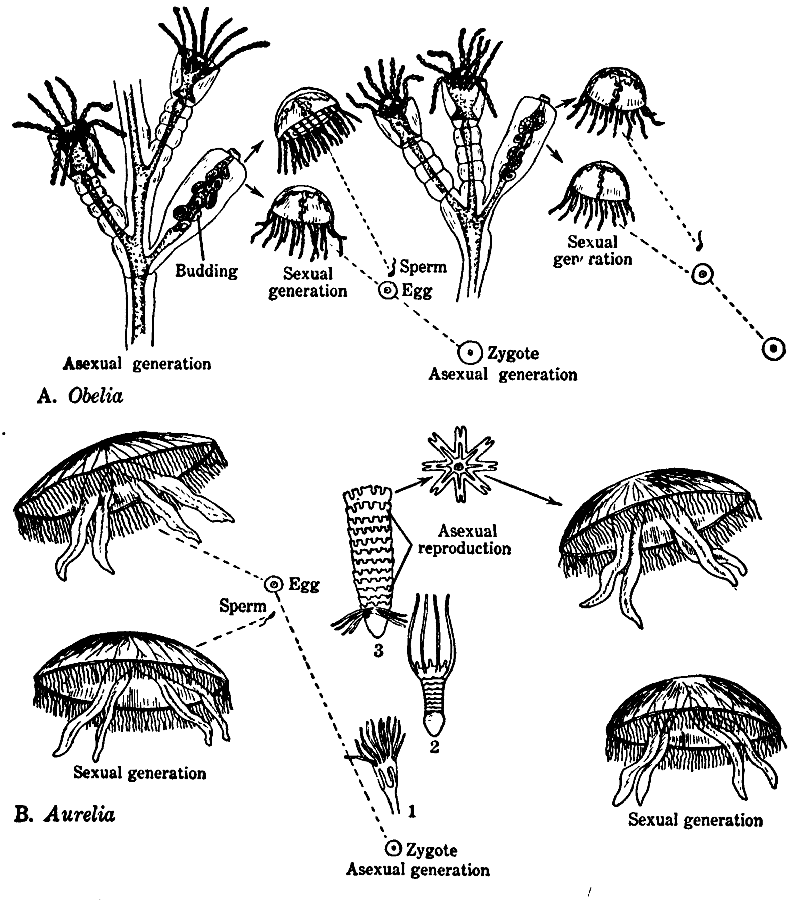


FIG. 210. Alternation of generations in a hydroid, *Obelia* (*A*), and in a jellyfish, *Aurelia* (*B*).

of a colony for special functions is an example of **polymorphism,** for the individuals making up the colonial animal *Obelia* appear in more than one form. A gonangium consists of a central stalk called the **blastostyle** on which produced by budding are small, rounded **medusa buds.** All these structures are enveloped by a globular transparent covering, the **gonotheca.** The asexually produced medusa buds escape through an opening in the end of the gonotheca and swim away

to live their own free, independent life. A study of Figs. 209 and 210 will show that the medusas, superficially, do not resemble the hydranths of the parent colony very closely but that they actually have many points in common.

The medusas are either male or female. In reproduction, the zygote does not develop into another medusa but into an *Obelia* colony (Fig. 210). In other words, the children resemble their grandparents. We have seen that the fixed *Obelia* colony reproduces asexually by budding, giving rise to a new generation in the form of the medusas which in turn reproduce sexually a new generation which is the colonial *Obelia*. This phenomenon, known as **alternation of generations,** is found more or less well developed in most of the Coelenterata except the sea anemones and corals (*Anthozoa*).

Class Scyphozoa (*skyphos*—cup; *zoon*). The jellyfishes become much larger than the medusas of the Hydrozoa. Ordinarily they measure 3 or 4 inches in diameter, but some may be as much as 6 feet across (Fig. 211). Some of the real giants may measure 12 feet in diameter and have trailing tentacles more than 100 feet long. They swim about by undulations of the body and the waving of **oral**

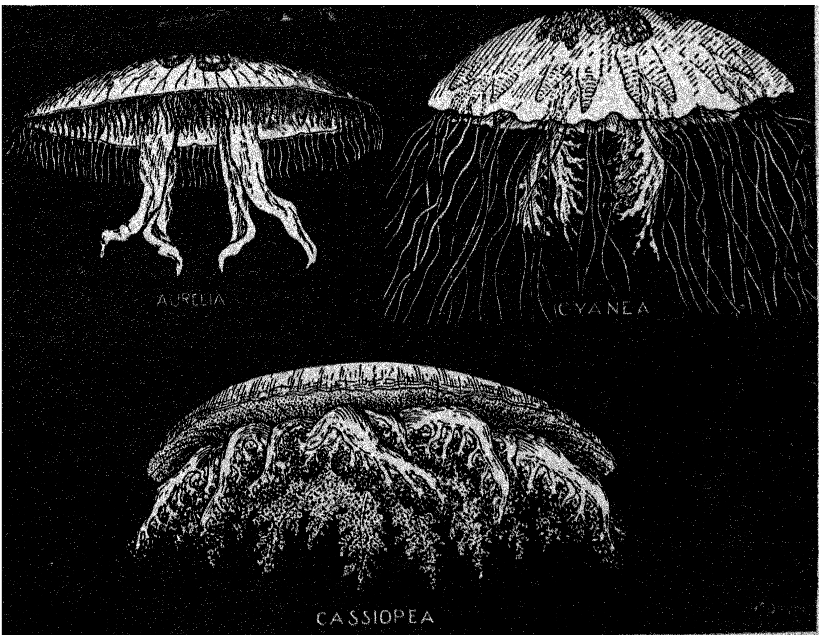


FIG. 211. Various jellyfish (Class Scyphozoa). Note the arms which assist in locomotion and the tentacles equipped with nematocysts. *By permission of the General Biological Supply House.*

arms or "lips" which extend outward from the corners of the mouth. In some forms the lips become several feet in length. The long arms as well as a fringe of tentacles around the margin of the animal are equipped with nematocysts, which solve the food and protection problems (Fig. 211). The jellyfish are of little importance to man, but they serve as food for whales and numerous fishes. However, the nutritive value must be exceeding small, for many jellyfishes are almost 99 per cent water.

As in the Hydrozoa, there is an alternation of generations in the Scyphozoa, but here the medusa stage is conspicuous whereas the polyp is small and relatively inconspicuous. The sexually produced zygote of the medusa grows into a polyp. As the polyp develops, a succession of grooves encircle the body and, by constriction and consequent transverse fission, eventually convert the polyp into a series of segments that resemble a pile of saucers. This is the asexual phase of reproduction. Finally, beginning with the top saucer, each segment frees itself and swims away to complete its transformation into an adult medusa or jellyfish (Fig. 210).

Class Anthozoa (*anthos*—flower; *zoon*). The Anthozoa are the sea anemones and corals (Fig. 212). There is no alternation of generations in this class, and the medusa stage is missing. The animals occur as polyps only. Some of the polyps may reach a diameter of 1½ feet, and many of them are brilliantly colored. Several circles of tentacles surround the **mouth,** which opens into a **gullet** (Fig. 213). The gullet leads to the **gastrovascular cavity,** which may extend up around it. The gastrovascular cavity is divided peripherally into small compartments by **mesenteries (septa),** some of which help to hold the gullet in place and increase the digestive surface of the gastrovascular cavity. Along the free edges of the mesenteries are found the **gonads** and the **digestive filaments** equipped with a type of **nematocyst.** The young animals pass through the early stages of development in the gastrovascular cavity, from which they escape through the mouth to find new habitations. Anemones may reproduce asexually by a type of fragmentation such as pulling apart into two halves or tearing off pieces of the body as they move about.

The corals resemble the anemones very closely in structure, but they secrete a skeleton of lime that protects and supports the body. Usually they are colonial and live in the more shallow ocean waters. Coral islands, atolls, and coral reefs (Figs. 212 and 213) have been formed from the broken coral "skeletons." The Great Barrier Reef extends for hundreds of miles along the coast of Australia. Other species, the so-called precious corals, are red or pink and are highly

FIG. 212. Corals from the Great Barrier Reef of Australia. *Courtesy of Nature Magazine, Washington, D. C.*

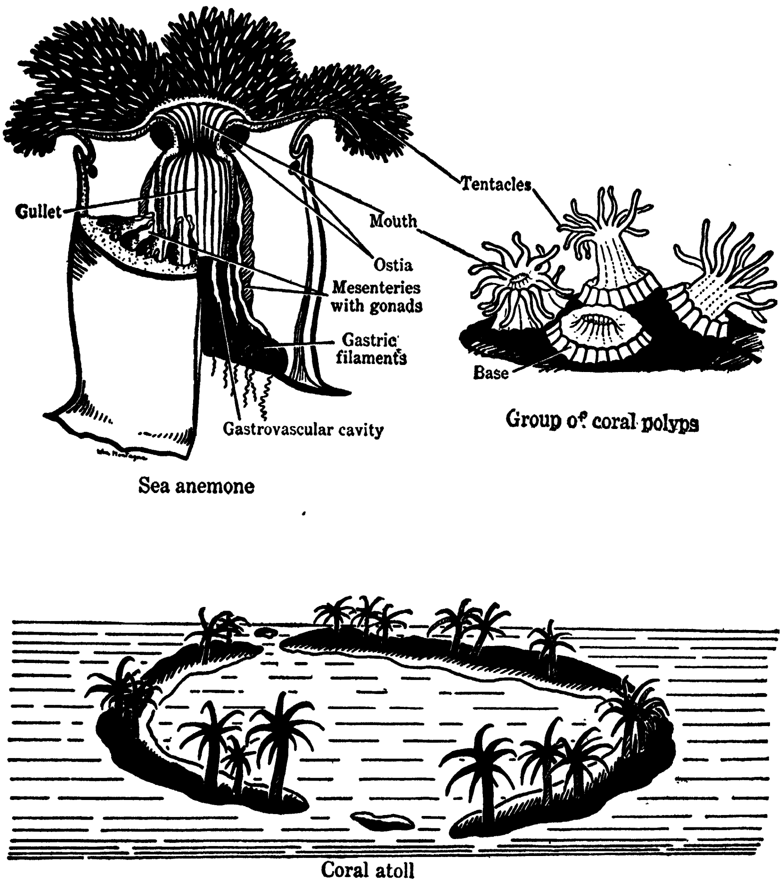


FIG. 213. Sea anemone and corals; class Anthozoa.

prized for necklaces, charms, and other ornaments. Some coral brings as much as $400 to $600 an ounce.

PHYLUM PLATYHELMINTHES

(*platus*—broad; *helmins*—worm)

The members of the phylum Platyhelminthes live in both fresh and salt water, and many of them are parasitic on man and other animals. They are, as the name implies, flattened worms which are bilaterally symmetrical. They have a digestive cavity the entrance and exit to which is through the mouth.

Class Turbellaria (*turbellae*—a stir). The little fresh-water worm *Planaria* is often found on the under surfaces of aquatic plants, rocks,

and debris. When discovered, it is usually contracted into a velvety mass and is often mistaken for a leech. When disturbed or dislodged from its hiding place in the water, it straightens out and is seen to be an animal generally less than an inch long with two simple eye spots on the broad or head end (Fig. 214). In the midventral surface of the body, about two-thirds of the distance from the head, is an opening, usually called the **mouth,** through which is often protruded the tubular pharynx **(proboscis),** at the end of which is the opening into the alimentary tract. The pharynx attaches to and pulls the food into the much-branched and pouched digestive tract. Here it is partially digested; the fine food particles are engulfed and digested by the cells in the digestive tract, and the food is distributed to other cells of the body by diffusion. There is no special respiratory apparatus. The excretory mechanism is made up of two lateral networks of fine tubes which open to the surface by minute pores. Lateral branches of this system end in tiny enlargements known as **flame cells,** each bearing a tuft of cilia. The beating of the cilia, resembling the flickering of a flame, causes a current of liquid to move through the tubules.

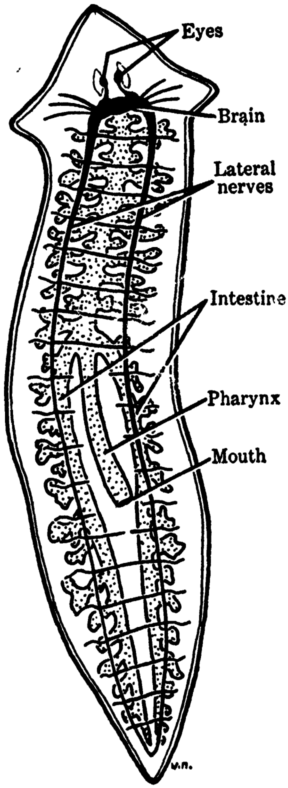


FIG. 214. *Planaria,* a free-living, fresh-water member of the Platyhelminthes (flatworms).

There is a well-defined nervous system consisting of **cerebral ganglia** ("brain") and two **lateral nerve cords** which are connected by numerous cross branches. Probably the **eyes** can distinguish only the difference between light and darkness.

Planaria is a true hermaphrodite, but its own eggs are never fertilized by its own spermatozoa, for the spermatozoa of two different planarians are interchanged. The eggs, containing an abundance of yolk, are laid outside the body and hatch there. *Planaria* reproduces asexually by transverse fission. It also has remarkable powers of regeneration.

The Turbellaria are of no special economic importance but are interesting as the only free-living examples of the phylum. These

animals have muscle, connective, and nervous tissue which have combined to produce well-defined organs and systems. In addition to the ectoderm and endoderm of the preceding phyla, they have a well-defined **mesoderm.** In other words, these Metazoa are **triploblastic** (*triplex*—triple; *blastos*—bud), while the Porifera and Coelenterata, although Metazoa, are only **diploblastic** (*diploos*—double; *blastos*).

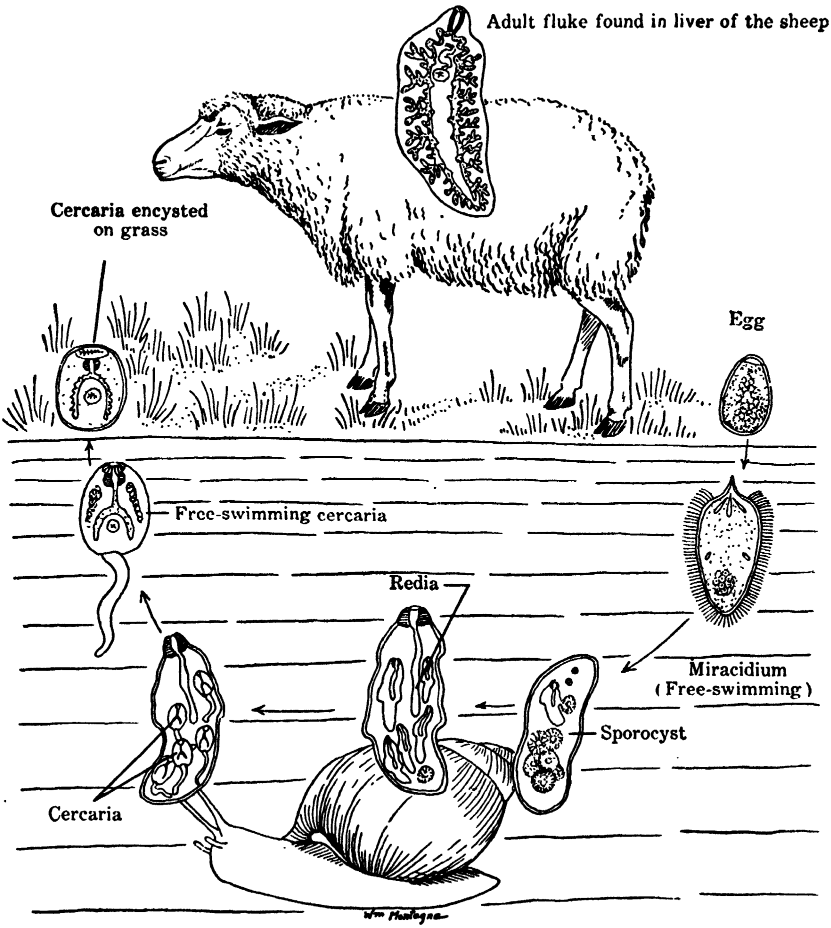


FIG. 215. Life history of the sheep liver fluke (*Fasciola*).

Class Trematoda (*trematos*—hole; *eidos*—form). These are all parasitic animals known as flukes, many of which have an interesting and complicated life history. They resemble *Planaria* in a general way but usually possess two **suckers,** one surrounding the mouth and another farther back on the body, a characteristic responsible for the

name of the class. The sheep liver fluke was first discovered by de Brie in 1379, who recognized it as the cause of a disease of sheep known today as "liver rot" (Fig. 215). Adult flukes have been found in other animals such as cats and dogs, and many forms are parasitic in man.

Human liver flukes are most important from man's standpoint. *Clonorchis sinensis* is found in the Far East, particularly in Korea,

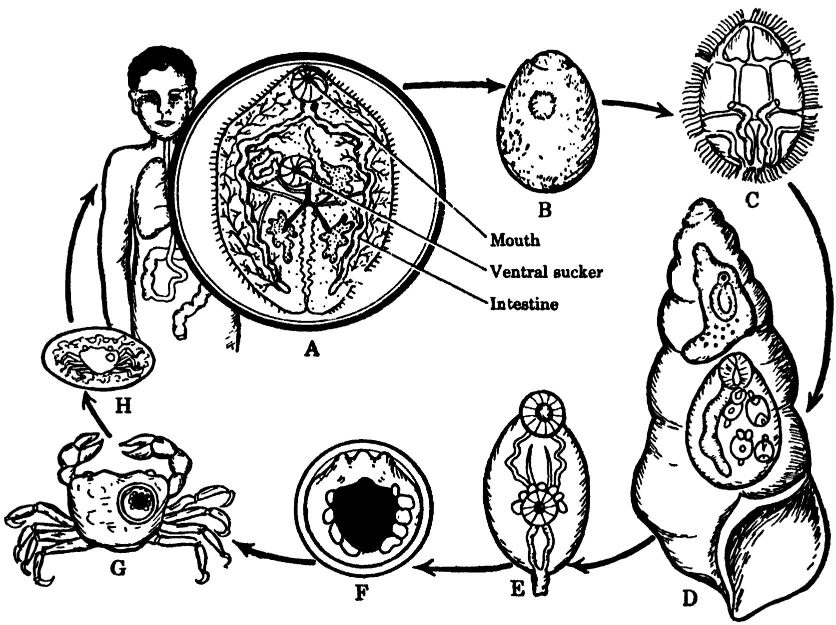


FIG. 216. Life cycle of the lung fluke (*Paragonimus*).

Japan, China, and parts of India. Man becomes infected when he eats that questionable delicacy—raw fish—in which these parasites are encysted. The adults live in the bile ducts of the liver and the gall bladder. The fluke is hermaphroditic. The fertilized eggs pass out of the host with the feces In most flukes, eggs hatch to produce a free-swimming form called a **miracidium.** The egg of this fluke, however, does not hatch immediately into a miracidium stage but is eaten by snails. In the snail, the miracidium emerges from the egg and transforms into a **sporocyst,** which in turn produces asexually another form called a **redia.** The redias finally produce **cercarias** which escape from the snail and bore into and encyst themselves in the flesh of the fresh-water fish. Man becomes infected by eating raw fish. Man

can escape infection by not eating raw fish and by proper disposal of human feces.

Lung flukes (*Paragonimus*) normally form hollow, cystlike tubes in the lungs. The cysts contain eggs, several worms, and broken-down tissues. The eggs escape from the bronchial tubes and are thrown off in the sputum. The miracidia enter a snail, in which they pass through the sporocyst stage and an additional stage known as the **redial** stage. The cercarias leave the snail and, if fortunate, encyst themselves in a crayfish or a crab. Man becomes infected by eating raw crabs. The infection is quite prevalent among the Japanese and Chinese (Fig. 216).

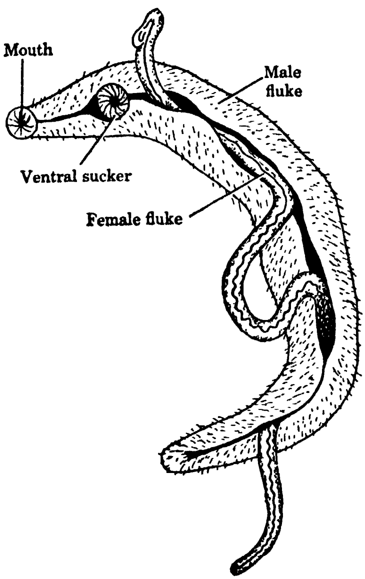


FIG. 217. Blood fluke (*Schistosoma*). Note the male carrying the female in its ventral groove. *Redrawn from Chandler, "Introduction to Parasitology." (After Looss and Leuckart.) By permission of John Wiley & Sons.*

Blood flukes (*Schistosoma*) in Egypt affect 65 to 85 per cent of the population. According to Christopherson, these flukes are "accountable more than anything else for the indolence of spirit, want of character, and backward condition of development of the Egyptian peasant." In some parts of Africa and tropical America, these parasites must be ranked among the most dangerous of human diseases. The eggs are laid in the blood vessels of the walls of the intestine or bladder, through which they bore and escape with the feces or urine, although some may be accidentally carried to the liver or lungs, where they set up inflammation. The egg must be in a watery medium, where it develops into a **miracidium** which immediately must find the suitable species of snail. In the snail the parasite passes through a **sporocyst** stage, finally emerging as a **cercaria** which swims around and penetrates the skin of the human individual who may be in the water bathing. The cercarias may also be ingested with drinking water. Eventually they find their way into various regions of the blood system (Fig. 217).

Intestinal flukes live in the intestinal tract of pigs and man, particularly the large intestine. Here they cause inflammation and

diarrhea. The intermediate host is the snail, and the cercarias encyst on water plants. Man becomes infected with some species of flukes by eating the stems, leaves, and "fruity" nuts of the water plants that contain the encysted cercarias, and with other species of flukes by eating raw fish.

Class Cestoda (*cestos*—girdle). The cestoda are the tapeworms, all of which are parasitic. Like the flukes, these animals have lost their sense organs and all power of locomotion. There is even no

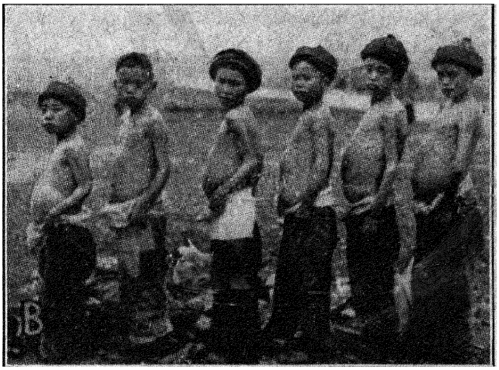


FIG. 218. Japanese children infested with *Schistosoma japonicum,* a blood fluke. *Reproduced from Culbertson, "Medical Parasitology," by permission of Columbia University Press.*

digestive tract, for they live literally in a river of digested food which needs only to be absorbed. Most of the common tapeworms have the same general structure and life history (Fig. 219). The animal anchors itself in the wall of man's intestine by its knoblike "head" **(scolex),** on which are several **suckers** and often **hooks** as well. The scolex is connected by the neck to a chain of segments called **proglottids.** There may be hundreds or thousands of proglottids extending for ten or twenty feet or, in the case of the broad fish tapeworm, sixty feet! Each proglottid has a complete set of male and female reproductive organs. The nervous and excretory structures of each proglottid form integral parts of the nervous and excretory systems of the entire worm.

New proglottids are continually forming in the region nearest the scolex, hence the mature proglottids are at the other extremity of the worm. The mature proglottids, containing thousands of eggs, are continually breaking off and being discharged with the feces of the host. Some of the discharged eggs, depending upon the species of worms, cling to the contaminated food of a cow or a pig. They hatch

in the intestine, and the hooked embryos bore their way into the blood vessels of the intestine and travel by way of the blood stream to the muscles of this intermediate host, where they reorganize to form what is known as **bladder worms** or **cysticerci** (Fig. 219). The cysticercus is a little sac of liquid with the scolex of the future worm turned into it. Eventually the intermediate host is killed and eaten by man. If the meat is poorly cooked, the bladder worms are unharmed. Once they get into man's intestine, they simply evert,

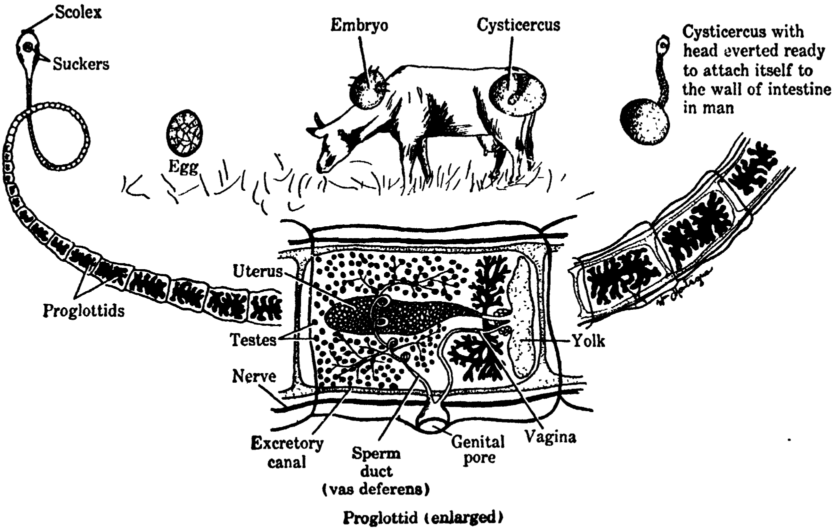


FIG. 219. Structure and life cycle of the beef tapeworm (*Taenia saginata*).

attach themselves, lose the bladder, and begin forming proglottids. The effect on the host is nervousness, anemia, and often loss of weight.

Some tapeworms, like certain of the flukes, have more than one intermediate host. The larva from the eggs of the "broad fish tapeworm" must be eaten by small crustaceans which in turn are eaten by the fish. Man then eats the raw fish. This tapeworm has recently been introduced into this country from Europe and is prevalent in the waters of Minnesota, northern Michigan, and Canada.

The method used for combating not only these parasites, but parasites in general, involves proper cleanliness in handling and preparation of food, proper disposal of wastes, and, whenever possible, the elimination of the intermediate host. The wide prevalence of parasites in the Orient is the result of the eating of uncooked food and the improper disposal of human excreta with consequent contamination of both the land and streams.

Often man is the intermediate instead of the final host for a cestode parasite. The larval stage of *Echinococcus granulosus* sometimes occurs in man and the adult in dogs. The larva develops into a "bladder" form on whose inner walls grow smaller bladders, each containing numerous "heads." This "hydatid cyst" may reach the size of an orange or even larger. Such cysts may be found in the liver, spleen, bones, or even the brain of man. They cause such disturbances as epilepsy. Constant seepage of fluid from the cyst may bring on attacks of allergy, nausea, and anaphylactic shock.

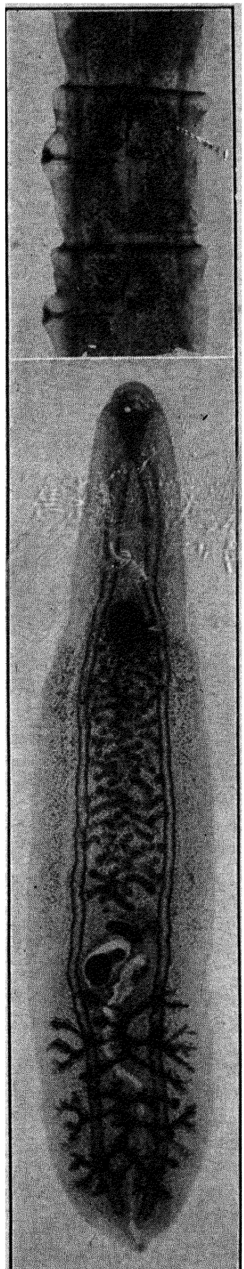


FIG. 220. *Upper,* proglottids of tapeworm; *lower,* human liver fluke. *Photos copyright by Albert E. Galigher.*

PHYLUM NEMATHELMINTHES

(*nema*—thread; *helmins*)

The nemathelminthes are round, slender, unsegmented worms usually pointed at both ends. They are found widely distributed in the soil, in salt and fresh water, and as parasites. The "horsehair" worm is probably the most familiar member of the phylum. It has been said that if we could wash away all the soil from a block of infected earth and leave the nematode worms in position, the outlines of the block would remain. Almost any collection of debris examined under the microscope contains these little worms, which can be seen whipping along by the contortions of the body.

In these animals, between the intestine and the body wall, there is a space which, not being lined by mesodermal epithelium, is not a true coelom. A tubular digestive system is present with an entrance through the mouth and an exit through the anus. The sexes are usually separate. The phylum is of greatest interest because it numbers among its members some important parasites of man and other animals.

Ascaris. One of the most common parasites of this phylum is *Ascaris,* a roundworm found in the intestine of man. These worms may vary from a few inches to a foot in length. *Ascaris* is found most frequently in children, particularly those living in the tropics. Some of these youngsters may harbor anywhere from two to three hundred worms. The worm is fairly robust with a simple tubular intestinal tract. There are no vascular or respiratory systems, and the nervous system is poorly developed, with no sensory organs pres-

FIG. 221. *Ascaris* embedded in the bile passages of the human liver. *Photograph furnished by Army Medical Museum, Washington, D. C.*

ent. The worm is protected against digestion by a heavy outer horny cuticle. The bulk of the worm is occupied by the sex organs, for its main business in life seems to be to eat and reproduce.

The female *Ascaris* really lays eggs, as many as 200,000 a day, and she works almost every day! The eggs pass out with the feces, and in each egg a tiny worm develops. After a time the eggs get into man's body via fresh vitamin-rich vegetables—improperly washed—in bad drinking water, and on soiled hands. The eggs hatch. The young larvas tour the body via the blood stream. Eventually they bore from the blood vessels of the lungs into the bronchial tubes. They work their way up to the pharynx and are then swallowed and pass into the intestine, where they feed on digested food. Quite often they produce no ill effects, but sometimes the host is nervous, anemic, and subject to epilepsy and dyspeptic disorders. Real trouble arises when the wanderlust strikes these worms and starts them on a journey which may end in the liver or in the brain, where

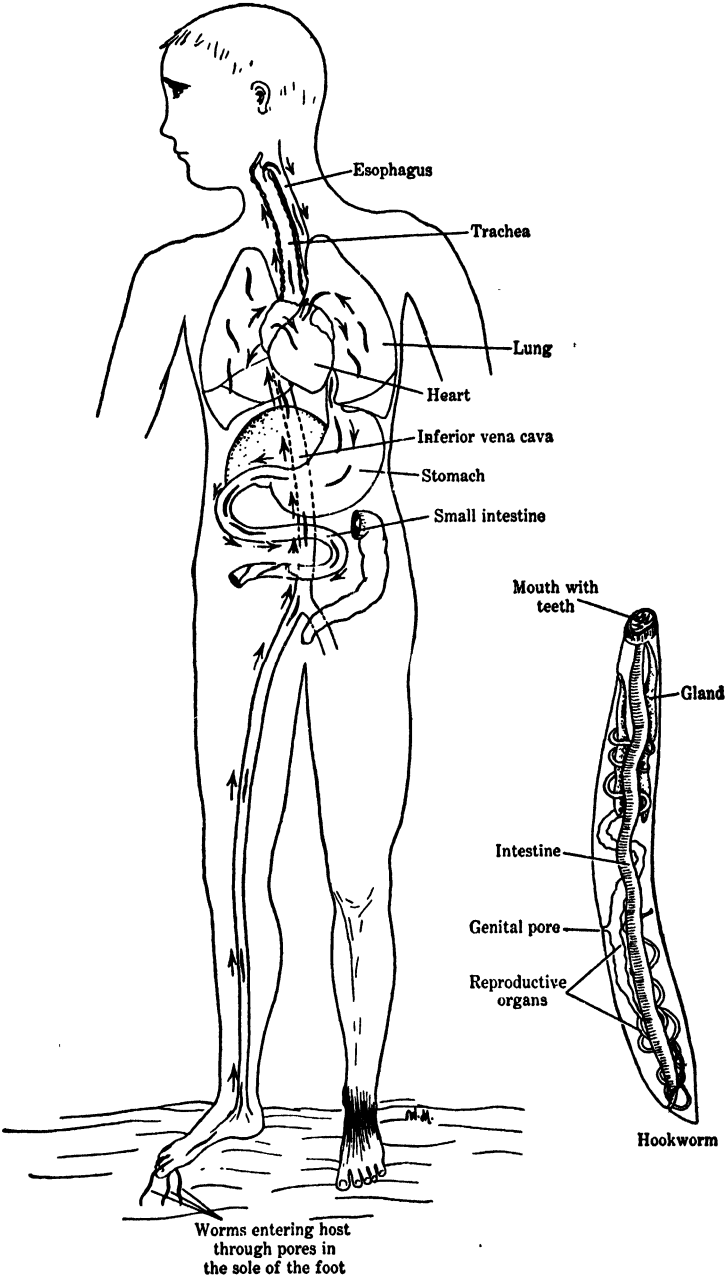


FIG. 222. The hookworm and diagram showing mode of infection. Arrows indicate the course followed by the hookworm from the time it penetrates the foot until it reaches the small intestine where it attacks the intestinal wall.

they form abscesses (Fig. 221). Sometimes they crawl up and escape through the mouth and nasal passages.

The **hookworm** (*Necator* in America) is a parasitic member of Nemathelminthes, common in the southern part of the United States.

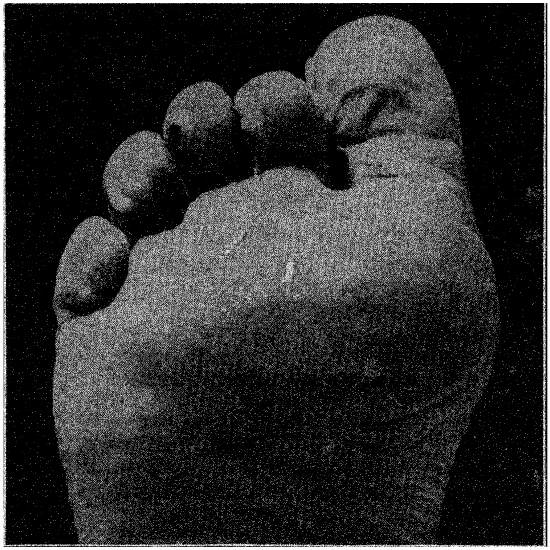


FIG. 223. Effects of hookworm. Note stunted growth and characteristic potbelly of the boy, and the sores on the toes or "ground itch," the result of entrance of the hookworm. *Photograph furnished by the Army Medical Museum, Washington, D. C.*

About 1900, Stiles made the assertion that much of the laziness and shiftlessness of the "poor whites" of the South was due to an infection with hookworm, dubbed by the newspapers in derision the "lazy germ."

The adult worm lives in the intestinal tract. It punctures the walls of the blood vessels of the intestinal walls and drinks the blood of the host. Loss of blood continues even after the worm has had its meal, for it injects a secretion into the wound which prevents clotting of the blood (Fig. 222). The continual loss of blood results in anemia, lowered vitality, and increased susceptibility to disease, particularly tuberculosis. Infected children are stunted mentally and physically. Today proper sanitation and medical treatment have

done much to eliminate hookworm infection and thus remedy social and economic conditions in the South (Fig. 223).

The female hookworm lays eggs at the rate of 8,000 to 10,000 per day. One stool may contain as many as 4,000,000 eggs. The eggs develop into tiny larvas which lodge in the soil. Now, if a barefooted person comes along and contact is made with the larvas, they may penetrate the skin to the blood vessels of the

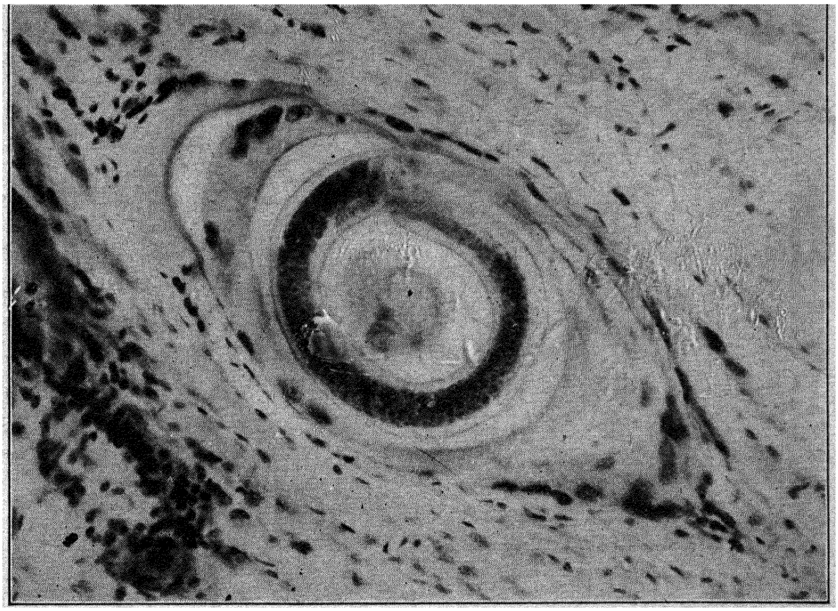


FIG. 224. Larva of trichina worm, *Trichinella spiralis,* encysted in striated muscle fibers in pork found in infected sausage. *Photomicrograph by permission of General Biological Supply House.*

foot. Thence they will travel to the heart and pass out into the lungs (Fig. 222). Here they bore through the walls, go up through the trachea to the mouth, and travel down the alimentary tract to the intestines, where life begins for the hookworm.

Trichina is another roundworm which in the adult condition lives in the intestinal tract of man or hogs. In the adult condition it causes no harm. In the intestinal tract, the female gives birth to living larvas, which then migrate to the diaphragm and voluntary muscles of the body such as those of the ribs, tongue, and eyes, where they coil up into a loose spiral and encyst (Fig. 224). When they are present in as large numbers as a billion or more they frequently cause the death of the victim. Man acquires these unwelcome visitors by eating poorly cooked pork. The pig becomes infected by eating frag-

ments of other pigs or rats and in time the larvas encyst in the muscles of the pig. Autopsies show that about 20 per cent of the population have been infected with trichina at some time or other. Contrary to popular belief the government does not inspect pork at the packing house. All pork should be thoroughly cooked. One ounce of fresh pork sausage may contain 100,000 encysted worms!

Wuchereria (*Filaria*) is a small worm that may be carried onto the skin by a mosquito when it bites a person. The worms penetrate

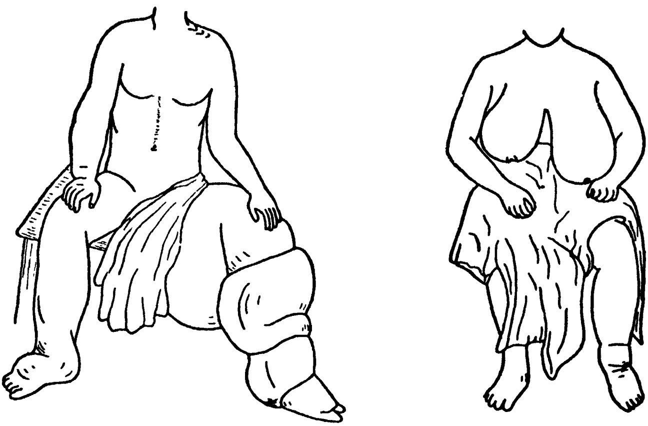


FIG. 225. Elephantiasis. Effects of infection with the round worm *Wuchereria* (*Filaria*). *Modified from Chandler, "Introduction to Parasitology." (After Manson.) By permission of John Wiley & Sons.*

the skin and dam up the blood and lymph channels of certain parts of the body, causing them to enlarge to many times normal size (Fig. 225). This disease is known as **elephantiasis.**

Pinworm (*Enterobius*) is a common infection particularly in children. The adult worms live in the cecum, appendix, and neighboring parts of the intestine. The eggs are laid and usually pass out with the feces. When members of a household are infected, eggs may be present not only on the hands of the members of the household but also on the clothing, bed linen, towels, floor, upholstery, and furniture. Infection takes place by entrance of the egg through the mouth.

African eye worm (*Loa loa*) is a human parasite found in western and central Africa. The adults live underneath the skin of man and creep from place to place, causing an itching and creeping sensation. Often they are found around the pupil of the eye (Fig. 227). The intermediate host of this worm is the mango fly. The young larvas invade the proboscis of the fly, and when the fly bites a person they

are often deposited in the skin of the host. These parasites cause little damage to the host other than discomfort.

Guinea worm (*Dracunculus*) is found parasitic in man from central Asia to Arabia and also in the East Indies, Egypt, and central

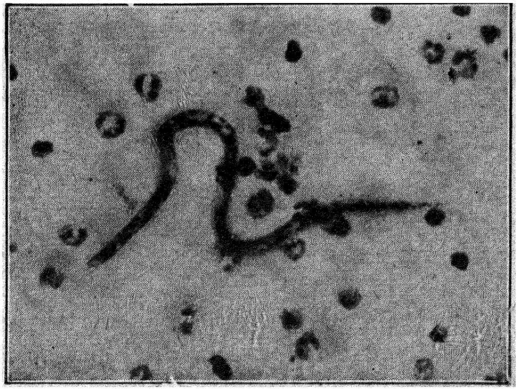


FIG. 226. *Filaria* worm. *Photomicrograph furnished by General Biological Supply House.*

Africa. In western India sometimes as much as 25 per cent of the population suffer from guinea-worm infections. The victims may suffer permanent deformities such as loss of limb or may even die from secondary infections. The female worm is the more important of the sexes. It reaches a length of 2.5 to 4 feet but is only 1 to 1.5 millimeters in diameter. It crawls around under the skin. The native doctor, using a split stick, grasps the worm firmly, and then by carefully twisting the stick he winds the worm around it and thus extracts the worm from the host. Care must be taken that this treatment is carried out under antiseptic conditions. The intermediate host in the life cycle of this worm is a small water animal called *Cyclops*. Man becomes infected by drinking water containing *Cyclops*. In western India the infection is always more severe in those communities served by "step wells" where the people wade down into the water to fill the con-

FIG. 227. *Loa loa* in the eye. (*After Fulleborn.*) *From Chandler, "Introduction to Parasitology." By permission of Asa C. Chandler and of John Wiley & Sons.*

tainers. It is during this time that the parent worm ejects her offspring through a hole in the skin of the host; also the drinking water may contain infected *Cyclops.*

Many other members of this phylum are parasitic on man, other animals, and plants. The fact should be emphasized that there are also many species of roundworms that are non-parasitic.

PHYLUM MOLLUSCA

(*mollis*—soft)

Nearly everyone is more or less familiar with such mollusks as clams, oysters, and various types of snails, but most of us are much less familiar with certain marine members of the phylum: the squid, the octopus, and the chambered nautilus. This phylum is a large group of invertebrates, and its members are used extensively for food. Mollusks vary in size from small creatures the size of a grain of rice to huge clams weighing as much as 500 pounds. The giant squids may reach a length of 50 feet overall. Mollusks are found both in fresh and salt water and on land.

Mollusks have bilateral symmetry. There is usually a ventral muscular **foot** commonly used for locomotion. The main part of the body is enclosed in a fold of tissue called the **mantle,** and in most of the animals a hard **shell** of calcium carbonate encloses the mantle. The three important classes of this phylum are the Pelecypoda, Gastropoda, and Cephalopoda.

Class Pelecypoda (*pelecys*—hatchet; *podos*—foot). These are oysters, clams, scallops, and mussels. They are characterized by having a hatchetlike foot, and a shell made up of two valves, hence the name bivalve. A brief study of the fresh-water clam will give a clear picture not only of this class but of the entire phylum as well. The "body" of the clam, that is, its vital structures, is enclosed within two shells or **valves** fastened together at the dorsal edge by a tough **hinge ligament** that will automatically hold the valves open (Figs. 79 and 228). Large **adductor muscles** attached to the valves are able to close them and hold them tightly together. Along the margins of the valves are a number of interlocking projections or **teeth** which assist in keeping the valves closed. The tightly closed valves afford the clam its only protection against enemies. Lining the valves and enclosing the soft body parts are the two **mantle lobes,** which serve not only to protect the delicate soft body but also to secrete the shell. At the posterior end of the clam the mantle lobes form two tubes leading into the **mantle cavity,** the space surround-

ing the body proper. The dorsal tube is called the **excurrent siphon,** and the ventral one the **incurrent siphon.**

Let us now examine the most important structures enclosed by the mantle. These, for the sake of description, we have called the "body." The most ventral region is made up of the **muscular foot,** which protrudes between the valves and slowly plows its way through the mud, pulling the animal along. Dorsal to the foot are the thin,

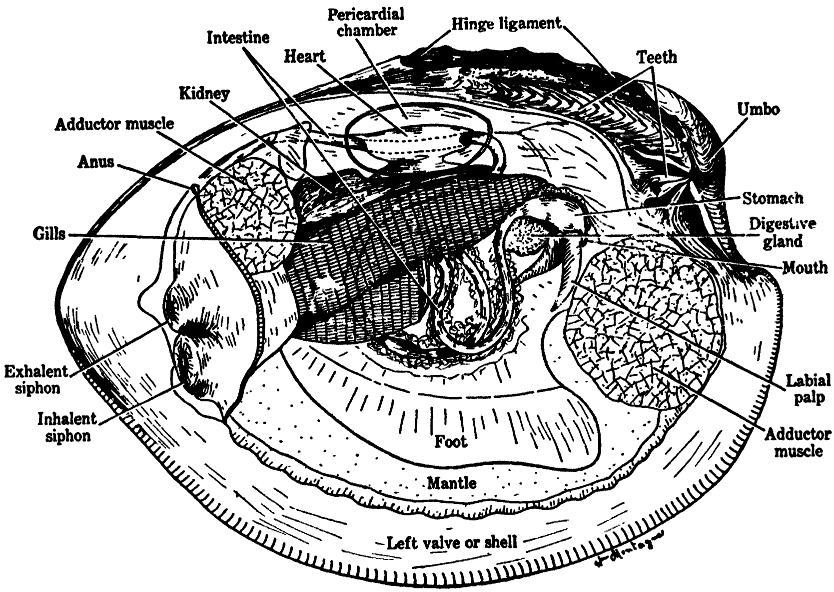


FIG. 228. Anatomy of the clam, quahog.

leaflike **gills** covered with cilia whose beating brings water through the incurrent siphon into the mantle cavity. The gills are perforated by numerous **pores** through which the water enters. Water then passes upward through the gills, and out through the excurrent siphon, carrying with it carbon dioxide and also excreta from the intestine (Fig. 228).

The clam has no head. The **mouth** is found at the anterior end between triangular flaps called **labial palps.** The food particles entangled in mucus secreted by the gills are moved toward the labial palps by ciliary action. The cilia of the labial palps direct the food into the mouth. Ciliary action carries it on to the **stomach** and through the **intestine.** The much-coiled intestine passes dorsally through the pericardial cavity and ends above the excurrent siphon.

Associated with the stomach is a **digestive gland** that aids in the digestion and absorption of food.

The clam has a well-defined circulatory system made up of blood vessels and certain spaces or **sinuses** in the body through which the colorless blood is pumped both forward and backward by the **heart.** The heart has two **auricles** and a **ventricle.** The blood in its course of circulation passes through the kidneys and the gills, where the

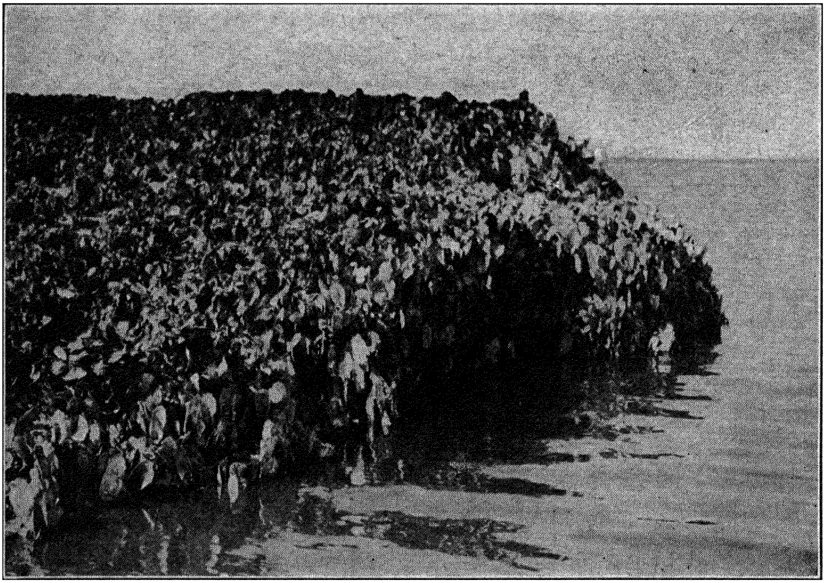


FIG. 229. Oyster reef. *Courtesy of Fish and Wildlife Service, U. S. Department of the Interior. Photograph by Galtsoff.*

wastes are extracted. In the gills and the mantle, oxygen is acquired and carbon dioxide is eliminated. In certain mollusks the mantle is a more important respiratory organ than the gills (Fig. 228).

The rather simple nervous system consists of three main pairs of ganglia. The **cerebral ganglia** ("brain") are located above the mouth. They are connected by nerve cords with the **pedal ganglia** in the foot and the **visceral ganglia** far back in the body. A pair of **statocysts** function as balancing organs, and a sensory organ (the **osphradium**) is thought to test water entering the mantle cavity.

The fresh-water mussel produces a large number of eggs. The eggs are collected in the gills, where they are fertilized by sperm entering the mantle cavity of the female with the incoming current of water. Here they remain until they develop into small bivalved

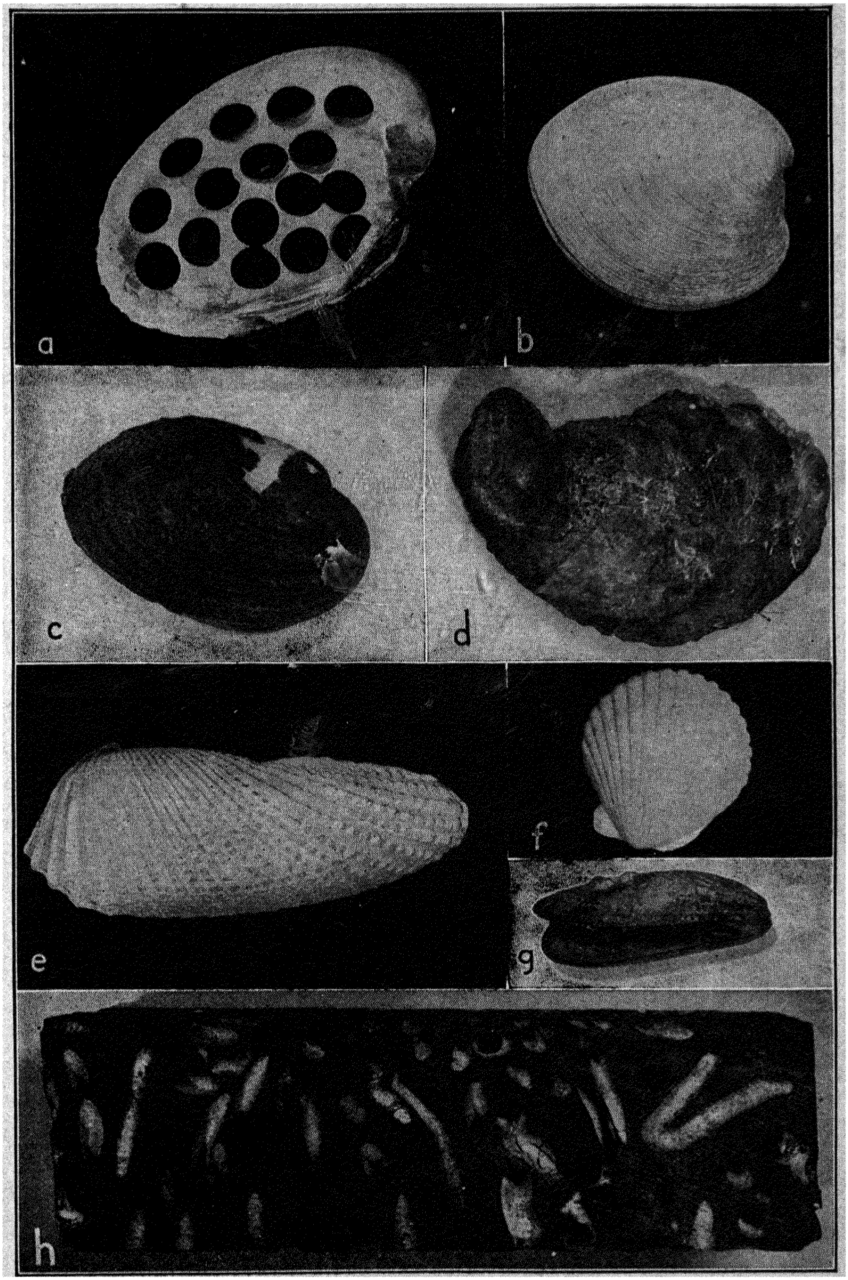


PLATE III. Class Pelecypoda (Mollusca). *a,* fresh-water mussel from which blanks for pearl buttons have been cut; *b,* hard-shell clam; *c,* fresh-water mussel; *d,* oyster; *e, Pholas; f, Pecten; g, Mytilus; h,* borings of the shipworn, a molluscan. *Photographs by Erwin Koval.*

larvas called **glochidia,** whose shells are usually equipped with small, rather sharp teeth. The glochidia leave the parent via the excurrent siphon and settle to the bottom of a pond or stream. Then, if some passing fish happens to brush them, they hook on, bore into the passerby, and live parasitically for a time. Within a few weeks, they undergo a remarkable transformation and finally drop out of the foster parent as young mussels. Meantime, the fish may have carried the young mussel quite a distance from its original home (Fig. 164).

The Pelecypoda are of great importance to man. The value of various clams, oysters, scallops, and others used for food amounts to millions of dollars (Fig. 229). The government reports for 1945 reveal that the annual crop of clams and oysters had a total value of $13,492,000. The shells of the fresh-water mussel are used extensively in the manufacture of pearl buttons. The 1945 reports show that the annual production of pearl buttons and pearl novelties such as knife handles, dolls, and lamps from the shells of mollusks amounted to $9,225,261.

The shipworm, really a pelecypod mollusk, using its shell as an auger, bores into ships and piling along the ocean, causing a loss of thousands of dollars. Nor should it be overlooked that some of the Pelecypoda form pearls.

A pearl is formed when a grain of sand, a dead parasite, or even a shot gets between the valve and the mantle. The irritation causes the mantle to cover the foreign object with smooth, non-irritating mother-of-pearl, and the end result is a pearl. Sometimes little metal images of Buddha have been introduced into a clam and the animal returned to the water. In due time the supposedly miraculous pearly Buddhas are removed and sold to the believers.

Class Gastropoda (*gaster*—stomach; *podos*). This group of mollusks includes those animals which usually have a spirally coiled shell and a flattened oval foot. In some forms the shell is missing. Gastropods are found in both fresh and salt water, and on land. Probably most of us have seen a snail with its shell on its back, on the sides of an aquarium or in the garden, moving slowly along by a series of wavy muscular contractions of the broad ventral foot. Snails smooth their pathway by laying down a very necessary layer of slime, which pours from an opening on the anterior end of the foot.

The foot is not the only prominent organ in the members of this class, for there is also a very definite head region with **eyes** located on the tips of projecting **tentacles** (Fig. 230). Other tentacles may be present near the mouth. The mouth is equipped with a tongue, which is modified to form a flexible file-like rasping organ called a

radula (*radere*—to scrape). Mollusca is the only group in the animal kingdom where this structure appears. This device plays havoc with garden vegetables, and the radula of a marine mollusk, the oyster-drill, bores right through the hard shell into the soft tissue of the oyster.

Gastropods have digestive, nervous, excretory, and reproductive systems resembling, in a general way, those of the clam (Fig. 230). Of rather special interest are the breathing devices of this group. Some gastropods get their oxygen by means of gills. Others use not

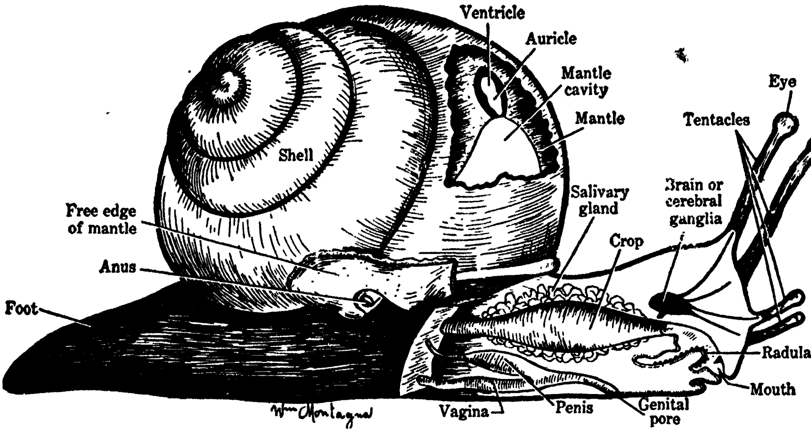


FIG. 230. Anatomy of the snail, a gastropod.

only the gills but also the mantle, which, in some of the land forms, is the sole breathing mechanism. Thus the mantle and its cavity serve as a "lung." Some snails are practically amphibious and may live submerged in the water or may be found perched on the emergent top of some aquatic plant.

We have already mentioned that some gastropods eat oysters and clams, and that slugs and other snails may be great pests of the garden and field. From the standpoint of disease, we have already noted that certain snails serve as intermediate hosts for parasites. Many snails are used as food, particularly abroad. It is estimated that as many as 200,000,000 snails have been consumed in Paris alone in a single season! They were purchased at prices ranging from fifty cents to two dollars per thousand. No wonder the government has suggested snail farming as a possible vocation in this country.

Class Cephalopoda (*kephale*—head; *podos*). The Cephalopoda are the most highly developed of the mollusks. Some members of the

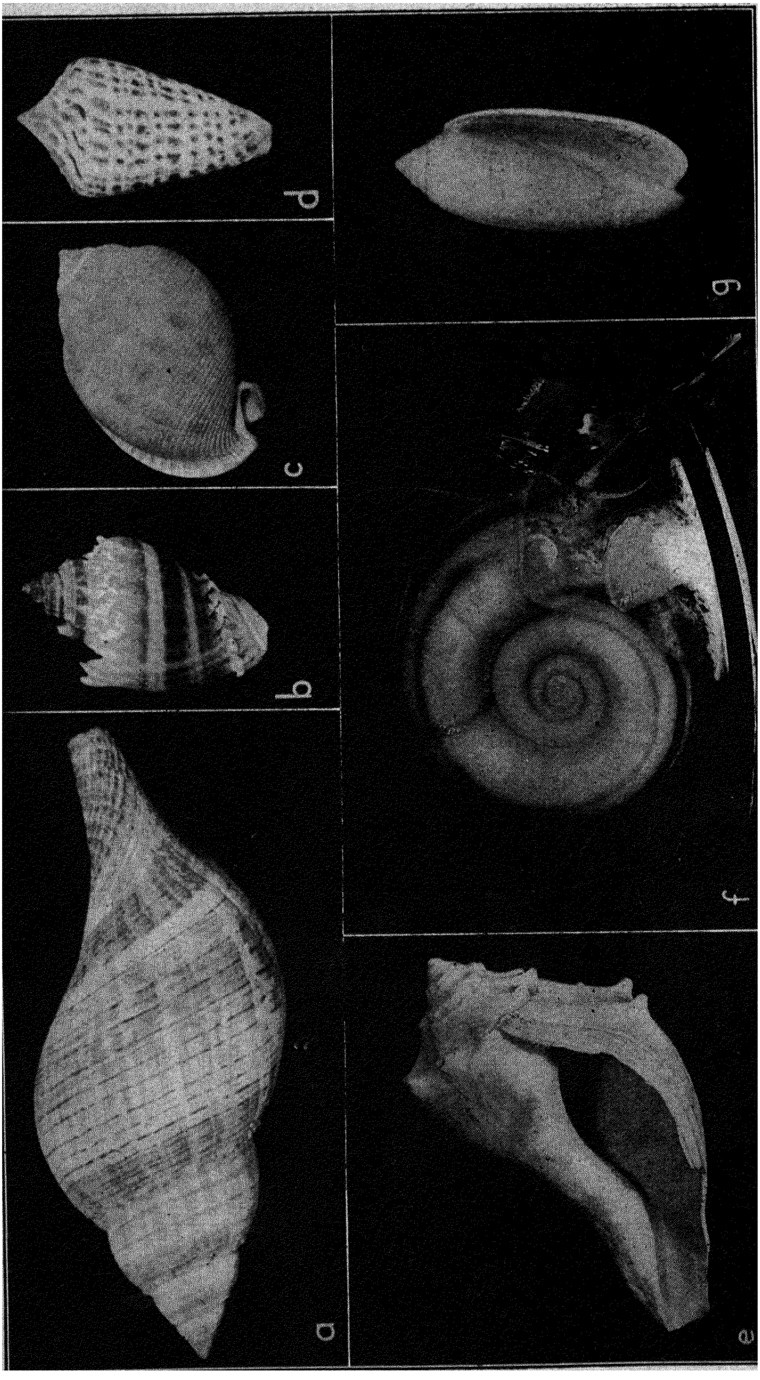


PLATE IV. Types of gastropods. *a, b, c, d, e, and g furnished by Erwin S. Koval. f, photograph of living snail, furnished by the General Biological Supply House.*

group possess an eye which is very similar to the vertebrate eye and may be image perceiving. The well-defined head of the animals in this group is really a grand combination of both foot and head. The mouth is located in the center of the foot! It is surrounded by a circlet of **arms** which are, in a sense, the fringe of the foot (Fig. 231). The mouth has not only a radula but also two horny, parrotlike

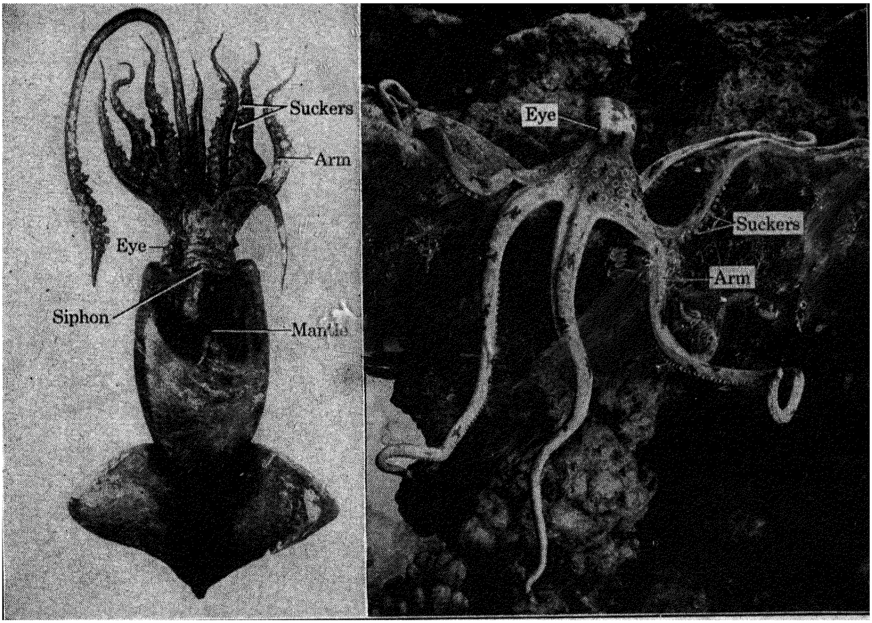


FIG. 231. *Left,* squid; *right,* octopus. *Photographs furnished by the American Museum of Natural History.*

jaws. Cephalopods capture their prey by means of the long arms, which, equipped with a series of **suckers,** grasp the prey, such as fish, and pull it into the mouth. Here the jaws and the radula do a finished job of tearing and grinding.

The shell is practically missing in this group except in the nautiloids. Partly for this reason most of the cephalopods are anything but sluggish. The bare muscular mantle of the squid and cuttlefish covers the body except for the head. The squid draws water into the mantle cavity and then shoots it out very forcibly through a small funnel **(siphon),** propelling the animal through the water like an exploding rocket through the air. A **lobed fin** aids in directing the movements. The octopus is more sluggish and crawls rather than

swims. When these animals are attacked by fishes and whales, they may shoot a cloud of ink out into the water and under cover of this "smoke screen" make their escape.

The Cephalopoda are of some economic importance. Despite many tales to the contrary, few of them attack man. Squids destroy the young fry of certain food fishes, but they in turn are often eaten by man. The cuttle bone in the cage of the pet bird came from a cephalopod called *Sepia*.

PHYLUM ANNELIDA

(*annulus*—ring; *eidos*—resemblance)

The worms of this group are very different from the ones already described. These annelid worms are round and made up of a series of very similar joints or segments called **somites.** Moreover, this rather extended division or **segmentation (metamerism)** has a definite bearing on the internal organization as well. This segmentation brings peculiar interest to the phylum for, as we shall see later, the two phyla ranking above the Annelida in structural complexity show some evidence of segmentation. It is also of interest to note that the members of this phylum have red blood and a kidney which in simplified form resembles that found in higher animals. Annelida include the common earthworm and many brilliantly colored and more complex aquatic forms, for annelids live not only on land but in fresh and salt water as well. Very few are parasitic.

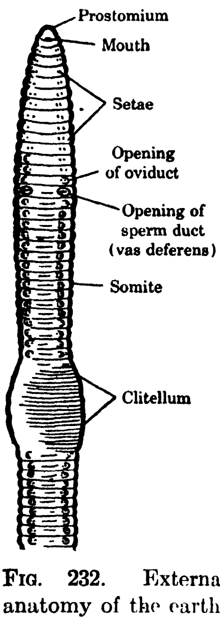


FIG. 232. External anatomy of the earthworm.

Class Chaetopoda (*chaite*—hair; *podos*). The common fishing worm belongs to this class, as do all those round, segmented worms that have stiff bristles or **setas** along the sides of the body. The anatomy and behavior of the earthworm should prove especially interesting because the animal is so much at home in practically all gardens and lawns.

The earthworm, called *Lumbricus,* lives in a subterranean burrow from which it emerges usually at night. It attains a length of some 10 or 12 inches and has 120 to 160 somites. A **mouth,** located at the anterior end, is overhung by a protruding upper lip called the **prostomium** (Fig. 232). The prostomium scrapes up particles of soil

and vegetable matter and pushes them to the mouth, through which they are sucked by the muscular **pharynx** (Fig. 233). There is some nourishment in the soil, but earthworms may obtain most of their food by devouring leaves or other parts of plants and even meat. This food and the soil pass from the pharynx through a narrowed tubular **esophagus** to an enlarged **saccular crop** where they may be stored until they are ground to a pulp in the tough muscular **gizzard.** From the gizzard the material passes into the long intestine, where much of it is digested and absorbed, the soil and indigestible residue being eliminated through the **anus.** This residue may be deposited at the mouth of the burrow at night as **castings.**

The absorbed food is distributed by means of the blood, which flows through a **closed** circulatory system. This system consists mainly of a **dorsal** and a **ventral blood vessel** which are connected by branches in almost every somite. The blood is forced anteriorly by the contractions of the muscular wall of the dorsal vessel and is further propelled into the ventral vessel by five pairs of muscular **aortic arches** which encircle the esophagus. Other vessels are present besides those described. The blood contains hemoglobin. This suggests at once that the blood provides for the distribution of oxygen and carbon dioxide. .The major portion of the oxygen-carbon dioxide exchange between the worm and its environment takes place through the moist skin. Membranous walls called **septa** divide the well-developed **coelom** into compartments corresponding to the "rings" seen on the outside of the worm. These compartments of the coelom are filled with coelomic fluid. In the fluid are ameboid wandering cells that may remove certain wastes. Most of the waste is removed from the coelomic fluid and transported to the exterior by the action of paired **nephridia** which are found in most of the segments (Fig. 233). Wastes may be removed from the blood by **chloragen cells** which line the coelom and cover the blood vessels. Some waste may be stored in the animal as pigment.

The seemingly simple movement of the earthworm is really somewhat complicated. The body wall has two sets of muscles, an outer layer of **circular muscle** fibers and an inner layer of **longitudinal muscle** fibers. Attached to the setas are certain muscle fibers by which they are moved. When the earthworm moves, the setas along the posterior end are protruded, anchoring that region in the burrow. The body is elongated when the circular muscles contract, exerting pressure on the relatively incompressible body fluids. Since the posterior end is anchored, when the circular muscles contract, the resulting elongation shoves the anterior end forward and lengthens

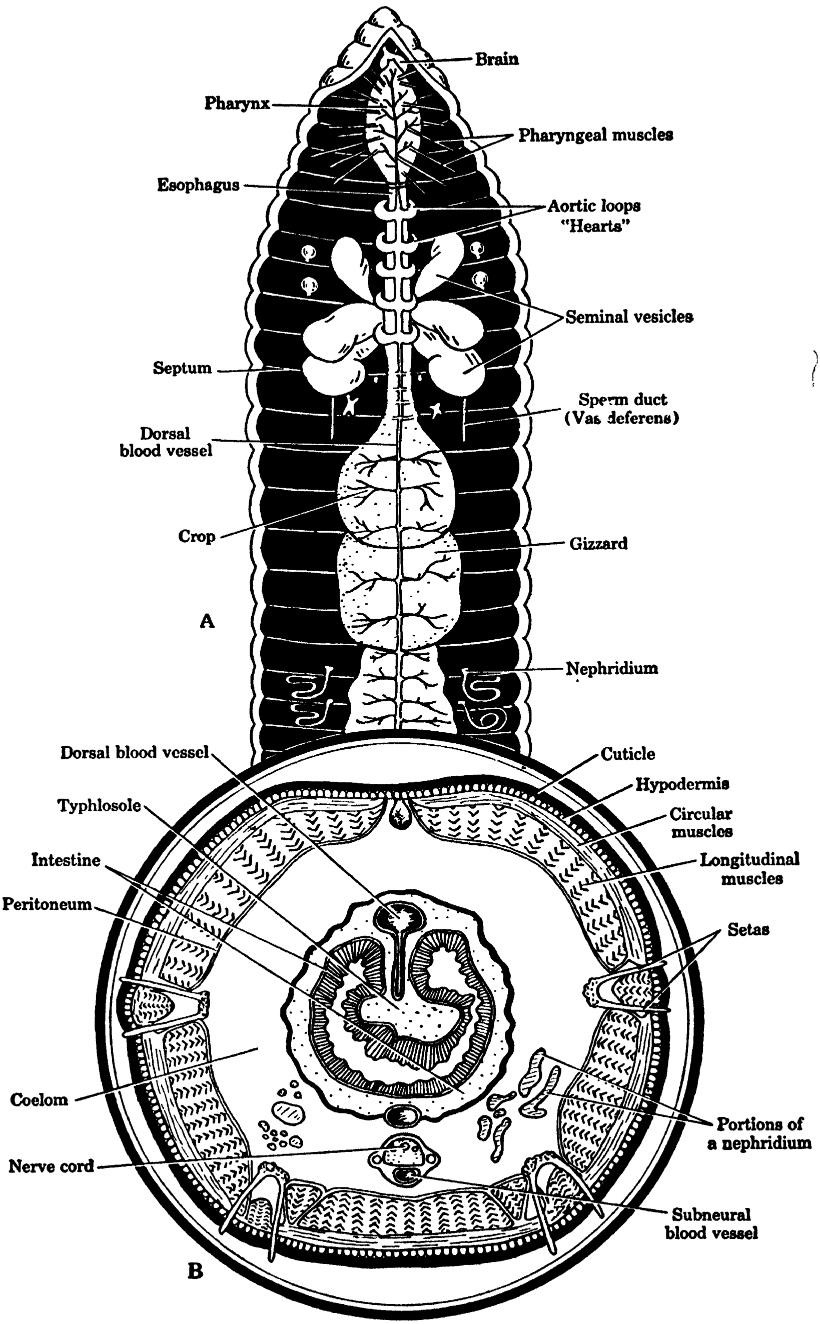


FIG. 233. Internal anatomy of the earthworm.

the worm. Next, the setas of the anterior region are anchored, the longitudinal muscles contract, and the posterior region is drawn forward. This process repeated brings about locomotion (Fig. 234).

The reproductive activities of *Lumbricus* are interesting. Although the animals are **hermaphroditic,** self-fertilization does not take place. Two worms come together with their anterior regions overlapping (Fig. 235). Mucus is secreted, forming a broad slime band that encloses about 28 segments of each worm and assists in the transfer of spermatozoa. Spermatozoa from each worm are deposited in the

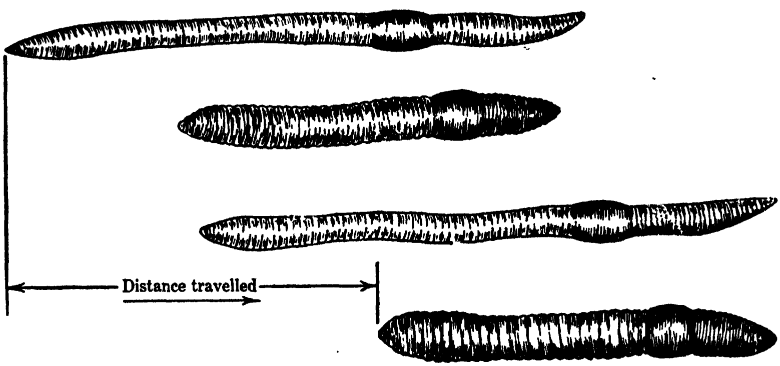


FIG. 234. Diagram illustrating mode of locomotion of earthworm by alternate contraction of the longitudinal and circular muscles of the body wall.

seminal receptacles of the other (Fig. 236). After this exchange of spermatozoa the worms separate. On each worm there is a swollen region (segments 32 to 37) called the **clitellum** (*clitellae*—saddle). This now gives off a secretion which forms a band or girdle of mucus. As the band is pushed forward by contraction of the body wall, it receives from the oviducts the eggs and, farther forward, the spermatozoa previously deposited by the other worm. The eggs are now fertilized. The slime band slips off the body as a cocoon, and in it the zygotes develop.

The earthworm has two dorsal anterior **cerebral ganglia** ("brain") connected to a ventral **nerve cord** that has an enlargement or **ganglion** in each somite. Earthworms are quite sensitive to light, especially at the anterior and posterior ends, and usually leave their burrows only at night. They are positively hydrotropic, a reaction that drives them to deeper haunts during dry and cold weather. They are apparently able to taste or smell at any place on the outer surface of their bodies. Earthworms are very sensitive to vibrations.

There are other chaetopods—relatives of the earthworm. One of the best-known chaetopods is the marine worm *Nereis*. This worm has a well-developed head with **jaws, eyes, tentacles,** and **sensitive palps.** Each somite back of the head region is equipped with a pair of paddles called **parapodia** (*para*—beside; *podos*), which are supported by a bundle of bristles. The parapodia are used not only for locomotion but, being well supplied with blood vessels, for breathing

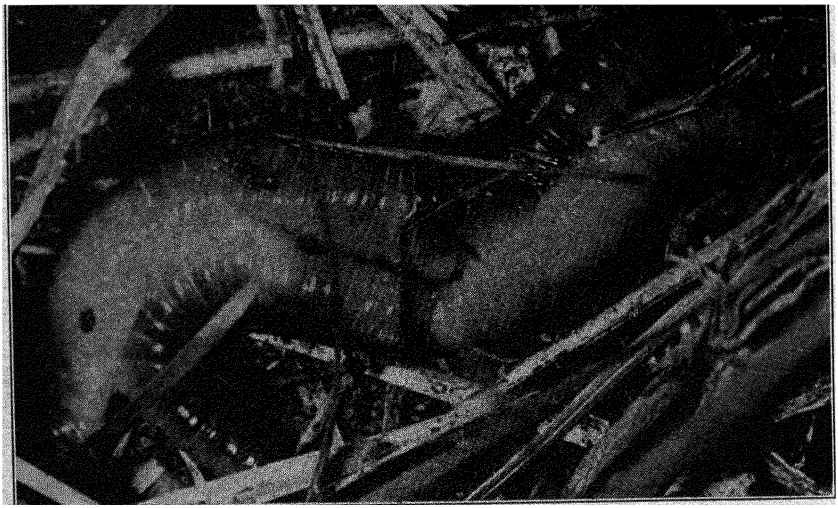


FIG. 235. Copulation of two earthworms exchanging spermatozoa. The worms held together by slime bands. *Photograph furnished by the General Biological Supply House.*

as well. Another ally of the earthworm, called *Lepidonotus,* has its back covered by a series of overlapping scales. Other chaetopods live in tubes made of sand, lime, or mucous secretions. In some of these tube-dwellers the head bears brilliantly colored tentacles and plumelike gills that may be projected from the tubes and readily withdrawn into the tube. Such worms often cover the bottom of the ocean, appearing like thousands of colored flowers.

Class Hirudinea. These are the leeches—annelids that are found on land as well as in both fresh and salt water. They are somewhat flattened, have no setas, and their segmentation is somewhat obscure. (See Plate V.) They have a **sucker** at each end of the body, and the one in front surrounds the mouth. Most of the leeches are blood suckers. The leech, by its anterior sucker, attaches itself to some animal and punctures a blood vessel. It then sucks the blood of its

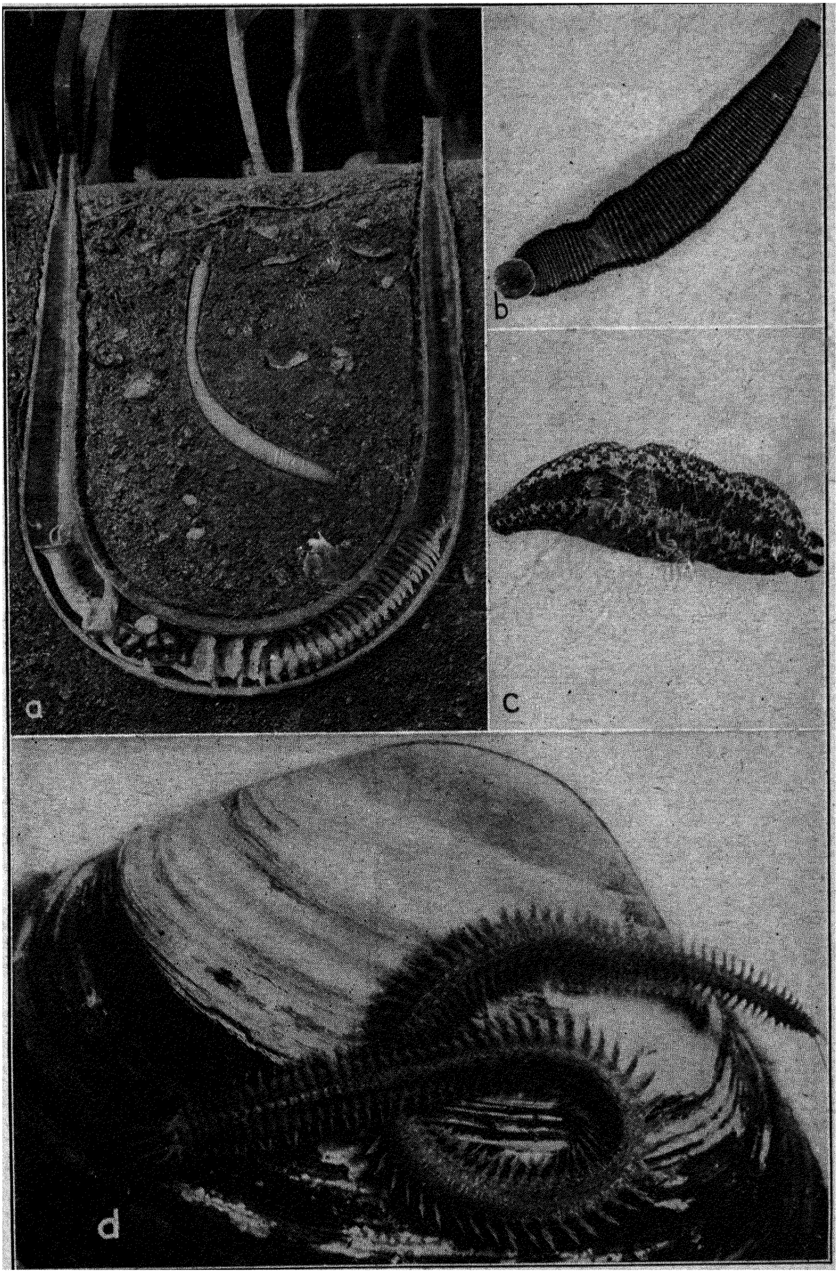


PLATE V. Various types of annelids. *a*, tube-dwelling annelid (*Chaetopterus*); *b* and *c*, medicinal leeches (*Hirudo*); *d*, clam worm (*Nereis*). *Photograph a furnished by American Museum of Natural History; b and c, by Mrs. P. S. Tice; d, by Nature Magazine.*

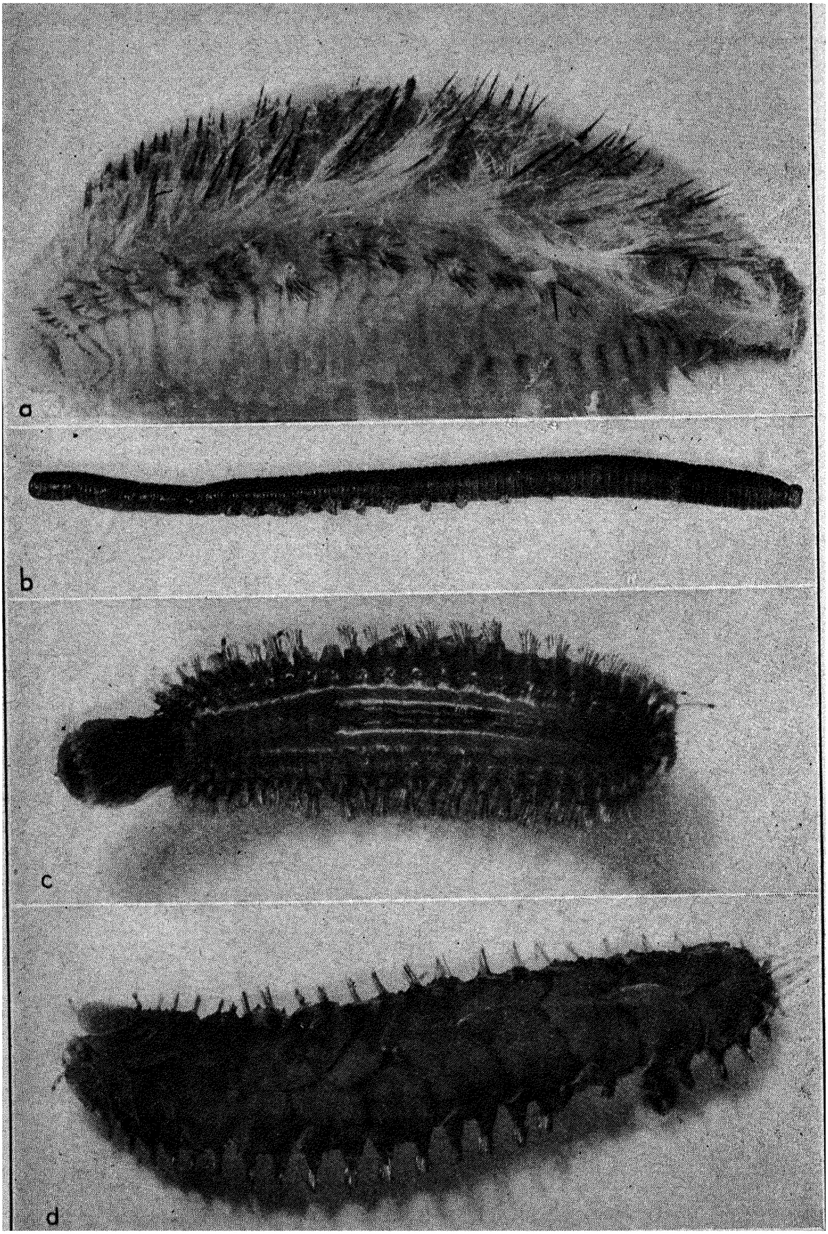


PLATE VI. Various types of Annelida. *a,* sea mouse (*Aphrodite*); *b,* lugworm (*Arenicola*); *c,* ventral and, *d,* dorsal view of *Lepidonotus.* Note the scales on the back. *Photographs by David Huntsberger.*

victim until the alimentary tract with its various side pouches becomes engorged. One meal will suffice for several months.

Earthworms are of indirect value to man in that they help to keep the soil porous, permitting water to enter more readily and assisting in the aeration of roots. The leaves, dragged into the burrows and only partly eaten and digested, help to build rich humus so necessary for plant growth. Charles Darwin estimated that the castings of

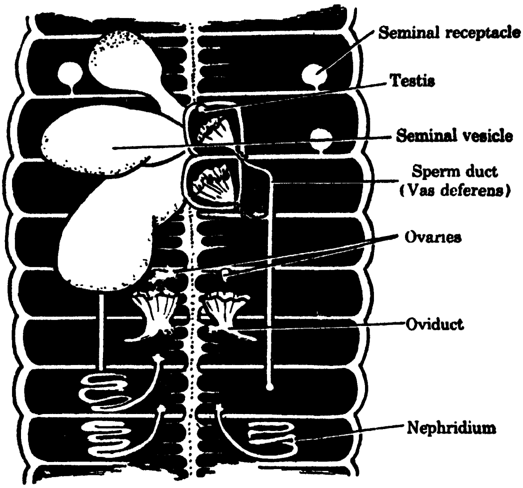


FIG. 236. Sex organs of earthworm.

earthworms brought to the surface one-fifth of an inch of new soil each year—18 tons per acre—and that a rocky field might have all its rocks buried in one generation. Certain annelids are used for food. The leeches are of little or no value to man.

PHYLUM ARTHROPODA

(*arthros*—joint; *podos*—foot)

Like the Annelida, arthropods have a serially segmented body, though in some animals several segments may be fused together. Unlike that of the annelids, the body is usually covered with a horny shell or **exoskeleton** which is thinner between the segments, a device insuring flexibility. This covering is composed mostly of chitin, a horny flexible substance which is waterproofed by a waxy surface layer. The exoskeleton is a differentiation of the cuticle. The cuticle in arthropods is differentiated into jaws, pincers, walking legs, lenses for the eyes, wings, and other specialized structures. Further, there

is a pair of somewhat long, **jointed chitinous appendages** on some segments, a characteristic that gives the name to this phylum. A better understanding of the anatomy and physiology peculiar to the members of this group will be obtained later from the description of the crayfish and grasshopper.

Arthropods are familiar to us as spiders, insects, crabs, scorpions, and the like. They are found in all habitats and, as far as different kinds or species are concerned, they are the most numerous of all the animals. Their great number and wide distribution should indicate a great variation in structure and habits among the members of the phylum. Of all the invertebrates, they are the most highly developed, not only structurally but also socially, for here are found the ants, white ants or termites, bees, and wasps.

Class Crustacea (*crusta*—a shell). Most of the 20,000 species of this group live in the water. The class contains such animals as shrimps, crabs, lobsters, pill bugs, and the common crayfish. Almost all members of the class breathe by means of gills and have two pairs of antennas, which are the distinguishing characteristics of Crustacea. The common crayfish is a typical arthropod and crustacean. These animals, living in lakes, streams, ponds, and underground water, eat almost anything and, in turn, are eaten by most fishes. The crayfish is completely protected by its somewhat heavy chitinous **exoskeleton** which is hardened by the addition of certain calcium salts. The fused head and thorax, known as the **cephalothorax,** is covered by the rigid chitinous **carapace** (Fig. 237). The **abdomen** is covered by a jointed segmented exoskeleton. This light protective armor, however, does not grow, and so the growing crayfish is compelled to shed it periodically. The molting crayfish, just after the shell is lost, are called "soft-shells." The animal swells up by the abnormal absorption of water, and, by the aid of stored lime, soon secretes a new shell.

As the crayfish walks slowly through the water on its four pairs of **legs,** it takes stock of its surroundings by feeling and smelling with its paired **antennas** and **antennules** located on the **head.** It looks around by moving its stalked **compound eyes** which bring to it mosaic images. Sometimes it goes into violent reverse by rapidly flapping its broad paddlelike **tail (telson)** (Fig. 237).

Two large modified walking legs **(chelipeds),** equipped with terminal pincers, catch prey or grasp the food and tear it up. Food is then transferred to the **mouth parts,** where it is further ground by the horny **mandibles.** It is then passed into the mouth and through the **esophagus** to the **stomach.** Here it is ground exceedingly fine

by three serrated teeth and then strained through a sieve of bristles into the **intestine** and into **digestive glands** for digestion and absorption. The digested food is absorbed partly by the digestive gland and partly through the intestinal wall.

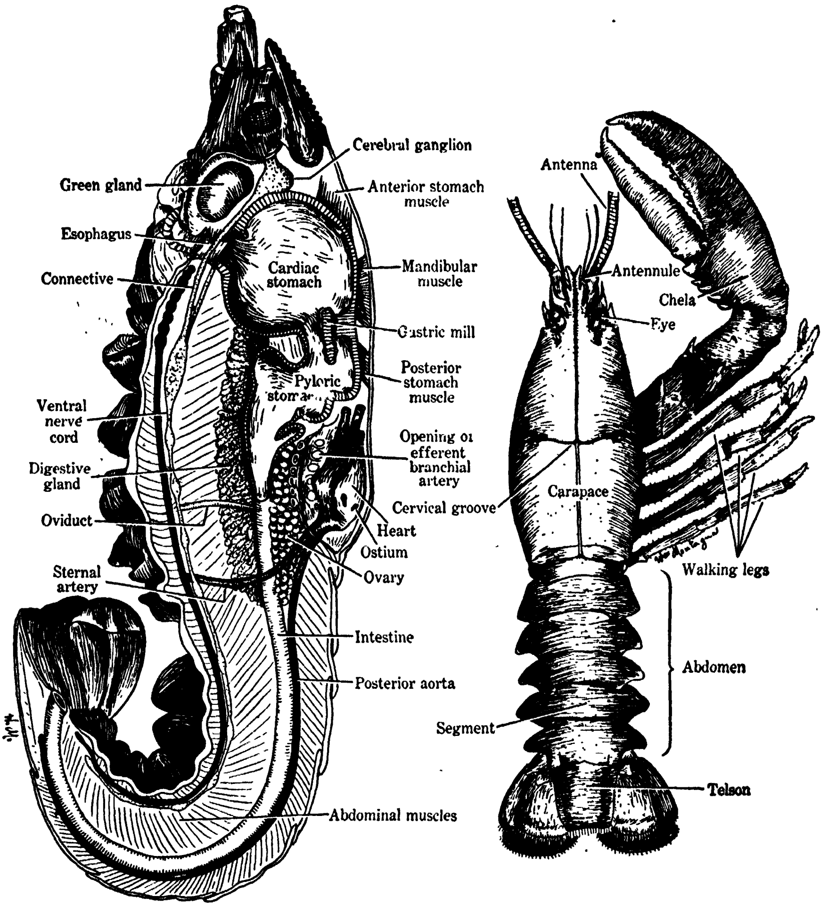


FIG. 237. External and internal anatomy of the crayfish.

The colorless **blood** circulates through the crayfish not only in vessels but also through **sinuses** or **hemocoels.** The blood is pumped through the body by a dorsal **heart** which fills with blood entering by little openings called **ostia.** When the heart contracts, the ostia are closed by valves. The blood distributes the oxygen which it receives as it passes through the feathery, plumed **gills** found under the edge of the carapace. Carbon dioxide is eliminated here also. Other

wastes of general metabolism are eliminated by means of the **green glands,** a pair of which are located in the head. The green glands function as kidneys.

The nervous system is much like that of the earthworm. There is a dorsal **brain** in the head near the eyes. A pair of connectives links the brain to the ventral **nerve cord** with its chain of **ganglia.** In the abdominal region, where the metameric arrangement of the animal is most apparent, there is one ganglion for each somite. However, in the region of the cephalothorax some of the ganglia apparently

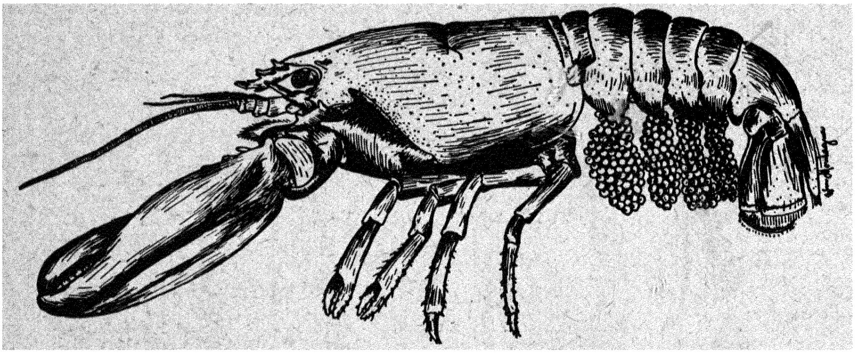


FIG. 238. "Berried" lobster. Note the eggs attached to the swimmerets on the ventral side of the abdomen.

have fused. From these ganglia nerves pass out to the mouth, appendages, and sensory organs (Fig. 237).

Crayfish are either male or female. The **testes** of the male are located under the heart. From them lead two twisting sperm ducts, which open at the base of the last pair of walking legs. In the breeding season, the male finds a female and transfers the spermatozoa to her. The eggs are laid in a gelatinous apron under the abdomen. The spermatozoa are released; the eggs are fertilized and fastened to the abdominal appendages where they develop into young crayfish. A female may carry between 300 and 600 eggs (Fig. 238).

Crustacea vary in size from microscopic forms to large lobsters and crabs. There is a wide range of variation in shape. One small fresh-water form called the fresh-water flea (*Daphnia*) is almost completely enclosed in a transparent chitinous shell. Fresh-water fleas use their antennas as swimming organs and move jerkily through the water. They have a dorsally placed brood pouch in which the young develop. Another rather common form is *Cyclops,* a small one-eyed crustacean whose anterior region is covered by a large

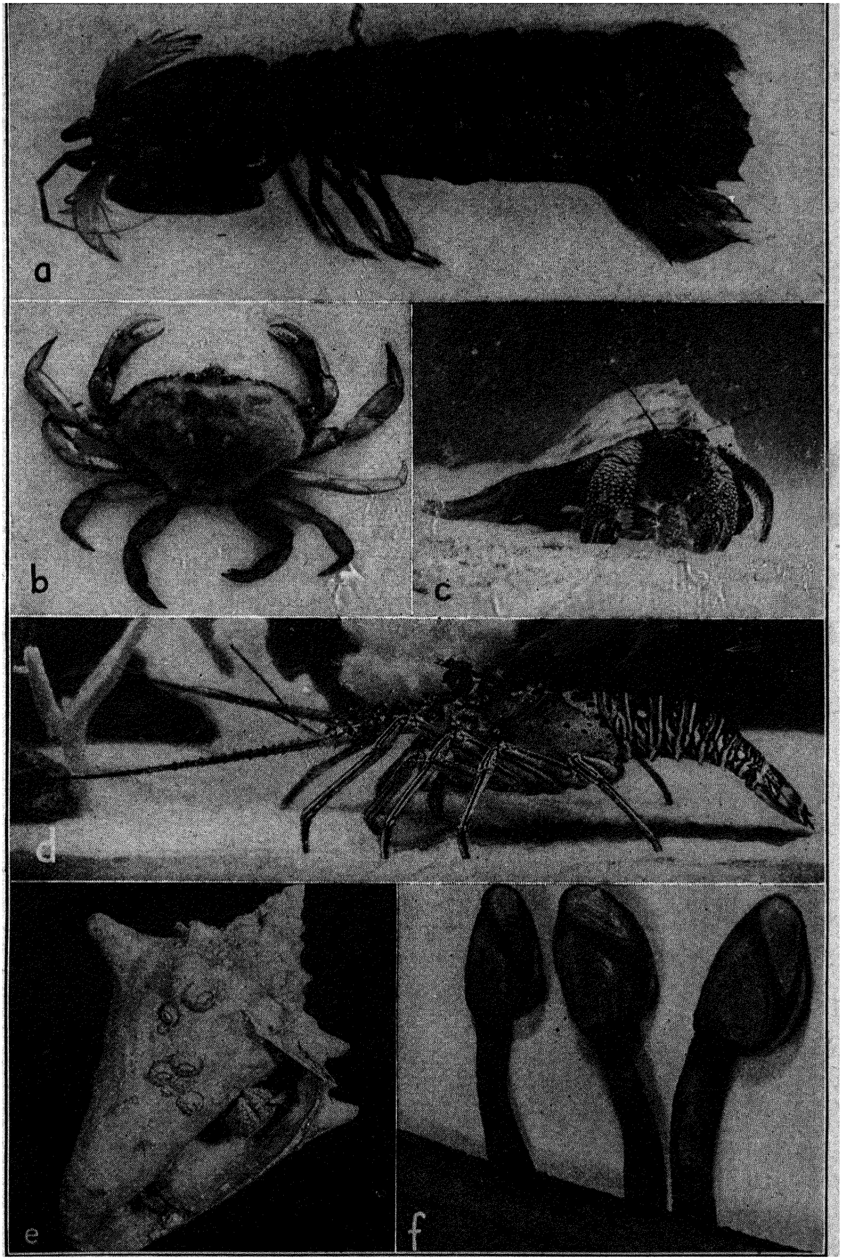


PLATE VII. Types of Arthropoda (Class *Crustacea*). *a, Squilla; b,* edible crab (*Cancer*); *c,* sea hermit crab in an empty conch shell; *d,* spiny lobster; *e,* hermit crab in conch shell on which are a number of acorn barnacles; *f,* goose barnacles. *Photographs a, e, f by Erwin Koval; b, by Fish and Wildlife Service, U. S.* Department *of the Interior; c and d, by John G. Shedd Aquarium.*

shieldlike carapace. Other species closely related to *Cyclops* live on the surface of the sea in large numbers, giving it a red appearance by day and causing bioluminescence at night. These small surface-living forms constitute a large part of the food of fresh- and salt-water fishes. Many crustaceans are parasitic, and some (*Sacculina*) are parasitic on other crustaceans.

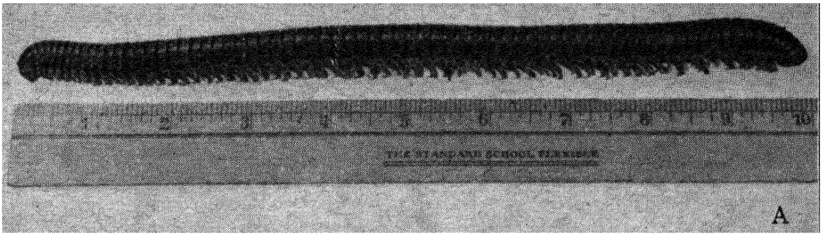
We should not dismiss the Crustacea without saying a word about barnacles which are mentioned in every salty tale of the sea. The ancestors of these sessile animals were motile. Barnacles have acquired protection by the formation of calcareous shell-like plates that were responsible for the former inclusion of this group with the Mollusca. The goose barnacle is attached by a long fleshy stalk, but in the acorn barnacle the stalk is missing and the animal is attached by its shell. Barnacles are found in large numbers strongly attached to wharves, hulls of ships, and rocks along the shore.

From the standpoint of food, shrimp are probably the most important members of the Crustacea. Reports for 1945 reveal that the annual crop of shrimp is 153,230,000 pounds having a value of $6,003,000. The annual supply of crab meat represents a value exceeding three and a half million dollars. The crayfish, an almost exact model of the lobster, is likewise used more and more extensively for food. Lobsters thrive for the most part along the north Atlantic coast, where the Pilgrims found the Indians using them for food. Commercial lobsters vary in size from 2 to 5 pounds. The weight of the largest lobster on record was 34 pounds. Formerly in Canada alone more than 100,000,000 lobsters were caught in one year, and in the United States a two years' catch amounted to as much as 11,750,000 pounds. Naturally, the slaughter of any animal at such a rate soon means scarcity if not extinction. Now the government is making an effort to insure a continuous supply of lobsters by regulating the type of trap used, by licensing lobster fishermen, by protecting berried lobsters—i.e., females with eggs—and by rearing lobsters in hatcheries.

Class Chilopoda (*cheilos*—lip; *podos*—foot) and **Class Diplopoda** (*diploos*—double; *podos*). Most of us have seen centipedes and "thousand-legged worms" scurrying away when we overturned logs or stones. These animals have no typical **thorax** or **abdomen** but possess a rather distinct **head** with **antennas** and **simple eyes.** Their **segmentation, chitinous covering,** and **jointed appendages,** as well as their internal anatomy, definitely mark them as arthropods. The centipedes, Class Chilopoda, with only one pair of appendages per somite, are active little animals that pursue and devour small insects and spiders after paralyzing them with a poisonous sting (Fig. 239). However, contrary to popular belief, the larger tropical forms do not inflict on man anything more serious than a painful wound. The millipedes, Class Diplopoda, with two pairs of legs per somite, are

rather slow-moving, non-poisonous vegetarians. They cause man little if any inconvenience.

Class Insecta (*insecare*—to cut in) or **Hexapoda** (*hex*—six; *podos*). It is doubtful that any group of animals is quite so varied in form, so interesting in life habits, and so vitally important economically



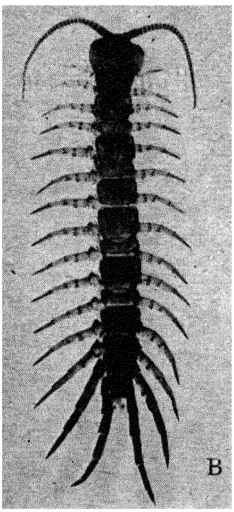


FIG. 239. Millipede and centipede *A*, Class Diplopoda, millipede; *B*, Class Chilopoda, centipede. *Photograph A furnished by Erwin Koval; B, by the General Biological Supply House.*

as insects. From the earliest times to the present, there has been a conflict between man and insects. The warfare grows more and more intense because, in the struggle for a livelihood, each must have the same vital things at the same time, and often there is not enough for both. Howard, one of our foremost entomologists, is of the opinion that man's very existence depends upon his gaining control of the insects. He points out that insects have been on the earth for more than two hundred million years as compared to man's brief stay of approximately one million. Now, in 250,000,000 years, animals can become much specialized and, to a high degree, well adapted to their environment. Whether man can stay on earth will depend upon his conquest of this mighty host, for it is a *mighty* host with probably more different species than all the other groups in the animal kingdom combined. However, not all insects are man's enemies, for, as will be seen later, he has some friends in the enemy's camp.

Insects differ from other arthropods in several distinctive features. Their bodies are divided into three main regions—**head, thorax,** and **abdomen.** They have **six legs,** all joined to the thorax. They breathe

by means of air tubes called **tracheae,** and they usually have **membranous wings** supported by veins.

The grasshopper, because it is an insect which is neither too primitive nor yet too specialized in form, is a desirable insect to study.

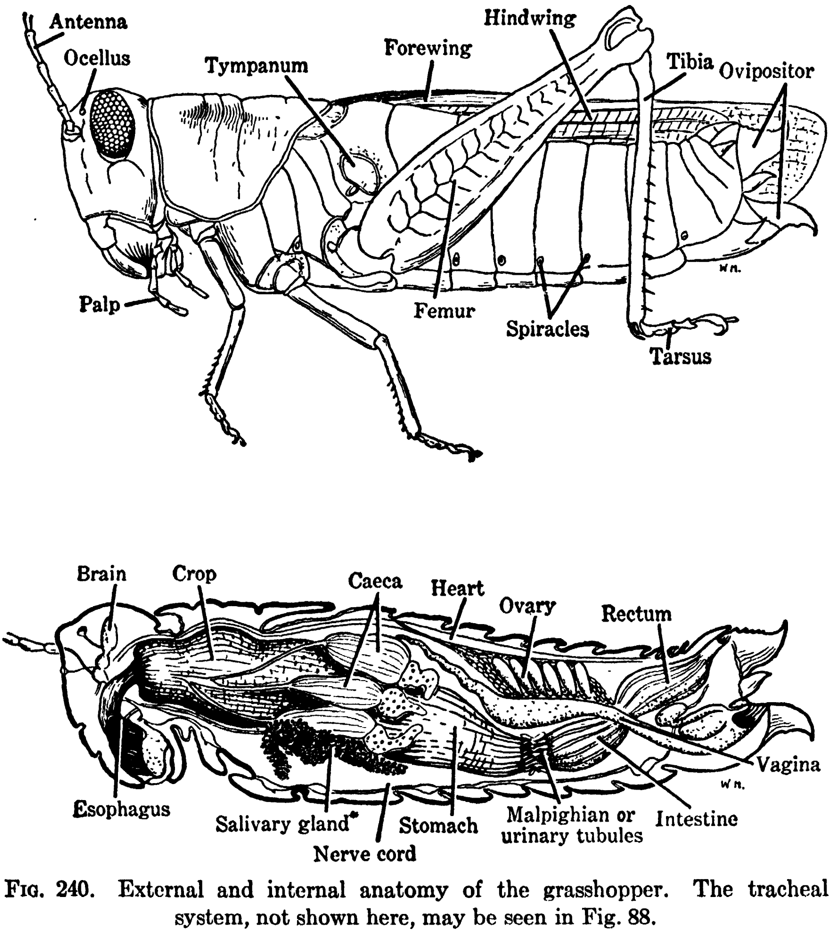


Fig. 240. External and internal anatomy of the grasshopper. The tracheal system, not shown here, may be seen in Fig. 88.

Grasshoppers were the locusts that plagued the Egyptians, and grasshopper plagues still appear in various parts of the world. They feed on green plants, and some species may swarm over hundreds of square miles of territory leaving denuded fields as they pass along. The grasshopper is a segmented animal with body divided into three regions, head, thorax, and abdomen. The entire body is covered with hard, shell-like chitin, which makes a rather rigid head and thorax;

but the abdomen is so constructed in jointed segments that it is fairly flexible.

On the head there is a pair of jointed tactile **antennas** in the basal regions of which are located the receptors of smell. A large **compound eye** stands out prominently on either side of the head. In

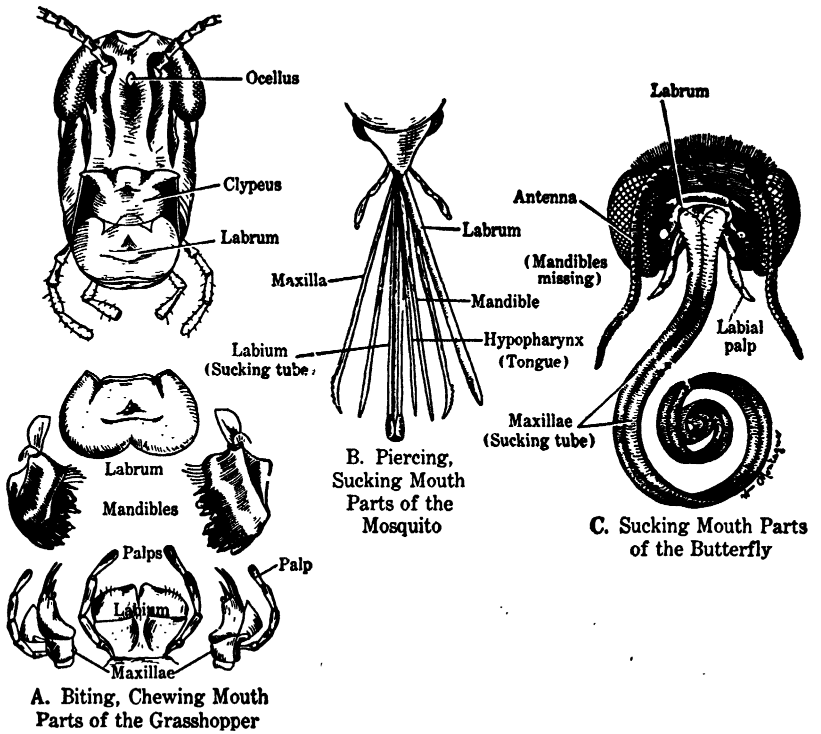


FIG. 241. Insect mouth parts. *A,* grasshopper; *B,* mosquito; *C,* butterfly. *B and C, redrawn from Parker and Haswell, "Textbook of Zoology," Vol. I. By permission of the publisher, the Macmillan Co.*

addition to these, there are three simple eyes **(ocelli)** (Fig. 240). The mouth is located on the ventral region of the head and is surrounded by a number of mouth parts. There is a **labrum** or upper lip covering a pair of lateral "jaws" or **mandibles** with which the grasshopper nips off pieces of vegetables. The mandibles are assisted in their task by a pair of **maxillae** which have a pair of jointed sensory **palps.** The food is held in place for all this chewing by the lower lip or **labium,** likewise equipped with a pair of **palps.** The tonguelike prolongation of the floor of the mouth is the **hypopharynx** (Figs. 240 and 241).

Attached to the thorax are three pairs of jointed **legs** and two pairs of **wings.** The last pair of legs, greatly elongated, is used in jumping. In running insects all the legs are similar, but in those that feed on other insects the legs may be adapted for holding the struggling prey. The wings are really chitinous evaginations or outgrowths from the body. Each begins as a saccular outpushing. The walls of the sacs press together to form two thin membranes in contact with each other. Here and there appear thickened ridges called **veins,** which serve to strengthen the wings. The hardened and thickened forewings of the grasshopper fold over and protect the thinner, fanlike posterior pair. In flying, the forewings are extended rigidly like those of an airplane, and the animal is driven forward by the posterior pair. The wings vary in different insects. In some of the primitive forms like the springtails and silver fish the wings are missing. Flies and mosquitoes have only one pair. The butterflies and moths have their wings covered with beautifully formed scales. Other variations will be pointed out later.

Along the sides of the segmented abdomen are small openings called **spiracles,** through which air enters to the breathing tubes or **tracheae.** The posterior segments are modified in the female, forming an **ovipositor** (Fig. 240). This is used to make holes in the ground, in which eggs air laid. The ovipositor of some insects may punch a hole in woody twigs or even the trunk of a tree; in other insects it is modified into a sting. On each side of the first segment of the abdomen is a small oval membrane called the **tympanum** or eardrum. How much an insect really hears is a question. Some grasshoppers make sounds with their hind wings, and crickets and katydids by rubbing together certain parts of the front wings.

The internal organs of the grasshopper and of all insects do not lie in a true coelom but in a blood-filled cavity known as a **hemocoel** (Fig. 240). An insect has all the systems represented which were studied in man and other animals. The food after being chewed and mixed with saliva passes down the **esophagus** to the **crop,** a storage organ, and thence into the **gizzard,** where it is ground and mixed. It then passes into the **stomach,** where it is further digested. Extending from the anterior end of the stomach are fingerlike outpushings, the **gastric caeca.** The food is absorbed for the most part in the stomach and caeca, which are modifications of the mid-gut region. In insects both the foregut region (esophagus, crop, and gizzard, when present) and the hind-gut regions are lined with chitin. The intestine is marked off into well-defined regions, the **small intestine** and the **rectum.** In some insects a crop is absent; a gizzard may be miss-

ing. In others which suck their food, the **pharynx** is modified into a muscular suction pump.

We have already called attention to the peculiar respiratory system of insects (Fig. 88). Grasshoppers breathe through the **spiracles,** which lead into a vast system of many-branched, spiral-walled tubes called **tracheae,** ultimately branching into the minute **tracheoles** that reach every cell of the body. This system provides for a much more direct gaseous exchange than the blood stream. The spiracles may be guarded by hair, plugs (to exclude matter), or closed valves. Some aquatic insects breathe by means of the gills; others carry under the water air bubbles clinging to certain parts of their bodies. The main excretory system is made up of fine **Malpighian tubules,** which lie in the blood sinuses and which extract nitrogenous wastes from the blood, voiding them into the intestine near its junction with the stomach. Although radically different in structure the Malpighian tubules have the same function as the kidneys of other animals.

The circulatory system of the grasshopper and other insects is very simple. The **heart** is merely a dorsal tube surrounded by blood which enters through **ostia.** The blood is yellowish or greenish in color, has no red corpuscles, and functions mainly in the distribution of food and wastes; it is distributed through the body by a system of spaces (hemocoeles). Various devices such as partitions serve to direct it in a fairly definite course through the animal.

The nervous system is very similar to that of the earthworm and crayfish. There is a dorsal **brain** joined to the **ventral nerve cord** by a pair of connectives. The ventral nerve cord begins anteriorly with the **subesophageal ganglion,** which controls most of the mouth parts. There are three **thoracic ganglia.** Much of the nervous activity of insects is of the reflex type. Apparently each ganglion has fairly independent control of a definite region of the animal. An insect whose brain has been removed lives, walks, and flies, but in a very erratic manner. We have previously described the functioning of the compound eyes and mentioned the fact that the antennas and mouth parts are the centers of taste and smell. The receptors of touch seem to be located in sensory hairs found on the body. Each of these special hairs has a tiny nerve fiber running to it. The "taste cells," or, more properly speaking, chemoreceptors, are thin-walled cones or plates which cover a tiny pore in the cuticle. They are kept moist by a secreting cell. Solid particles and gases are dissolved in the moist secretion, and the impulse is transmitted by nerve fibers. Insects are able to detect odors imperceptible to man. We have

already called attention to the ears or tympana of the grasshopper. They apparently are set in vibration by sound waves. In the mosquito it is thought that certain whorls of hair on the antennas serve as organs of hearing.

All insects are either male or female. Female grasshoppers are readily distinguished from the male by the **ovipositor.** The eggs leave the **ovary** by the **oviducts,** which unite to form the **vagina.** This opens to the exterior through the **genital opening.** Above this opening is a tubular **seminal receptacle (spermatheca)** in which the male deposits the spermatozoa during copulation. The spermatozoa are released to fertilize the eggs as they are laid. The male has two **testes.** Leading from them are two sperm ducts which fuse, forming a duct that opens to the outside. Various accessory glands may be present which aid in the transfer of spermatozoa from the male to the female.

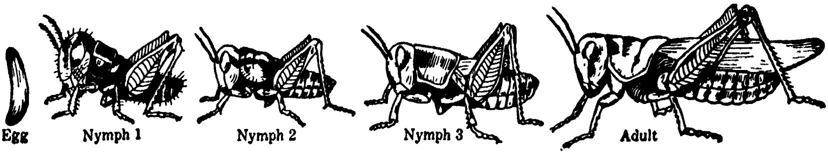
METAMORPHOSIS OF INSECTS. Many of the insects during their lives undergo remarkable changes in form; butterflies were once caterpillars, and shiny beetles developed from soft, wormlike grubs. The most striking changes of metamorphosis of insects occur in the external form of the body. Often there seems to be but little in common between the successive stages represented in the same insect. On the basis of these differences four distinct types of development are recognized (Fig. 242):

Development without metamorphosis. The young insects just hatched are practically of the same form as the adults. This type of development is found among such primitive insects as silver fish and springtails.

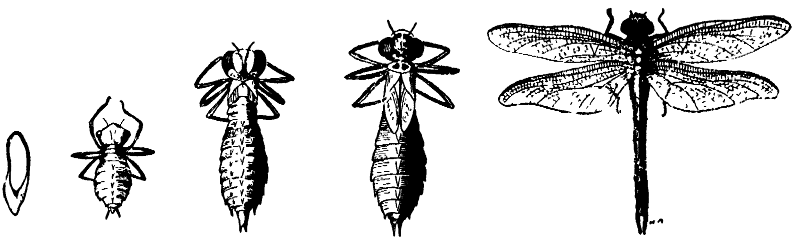
Gradual metamorphosis. The young insects, **nymphs,** resemble the adults in general form of the body and mode of life. The changes that do take place—growing of the body, wings, and genital appendages—are very gradual and never conspicuous between two successive **molts.** A young grasshopper undergoing gradual metamorphosis is wingless. Grasshoppers, cicadas, and true bugs have this type of metamorphosis.

Incomplete metamorphosis. The changes that take place are greater than those occurring in gradual metamorphosis and fewer than those of complete metamorphosis. The young insects **(naiads)** differ markedly from the adults in form of body and mode of life. The naiads are adapted for an aquatic life whereas the adults are terrestrial. Dragonflies, mayflies, and earwigs have this type of metamorphosis.

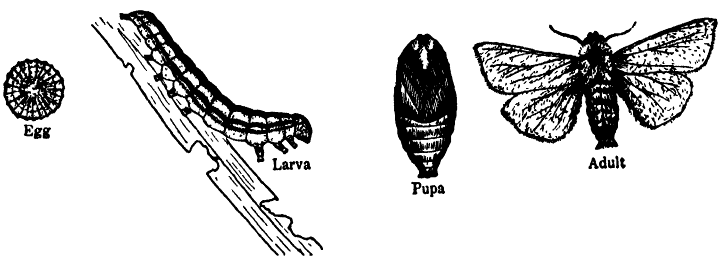
Complete metamorphosis. Insects that exhibit this type of metamorphosis undergo astounding changes in their young stages, and the young do not even remotely resemble the adults. The classic example is the butterfly, which hatches from the egg as a caterpillar that



Gradual metamorphosis of the grasshopper



Incomplete metamorphosis of the dragon-fly



Complete metamorphosis of the army worm

FIG. 242. Metamorphosis of insects.

transforms into a **chrysalis** or **pupa** from which it emerges as an adult insect. The pupa may be enclosed in a cocoon of spun fibers. Since so many different kinds of insects have this type of metamorphosis, the young stages are given different names: a young butterfly is a larva, a young beetle is a grub, and a young fly is a maggot. The term larva, in a broader sense, is used to denote immature insects of all kinds.

With these general facts in mind, we shall study some of the more important and interesting orders of insects.

ORDER ORTHOPTERA (*orthos*—straight; *peteron*—wing). This group of insects brings together some very "queer" and dissimilar specimens. Here we find roaches, grasshoppers, crickets, katydids, and such curious forms as the walking-stick and the praying mantis (Fig. 243). These insects have chewing mouth parts. The males of some

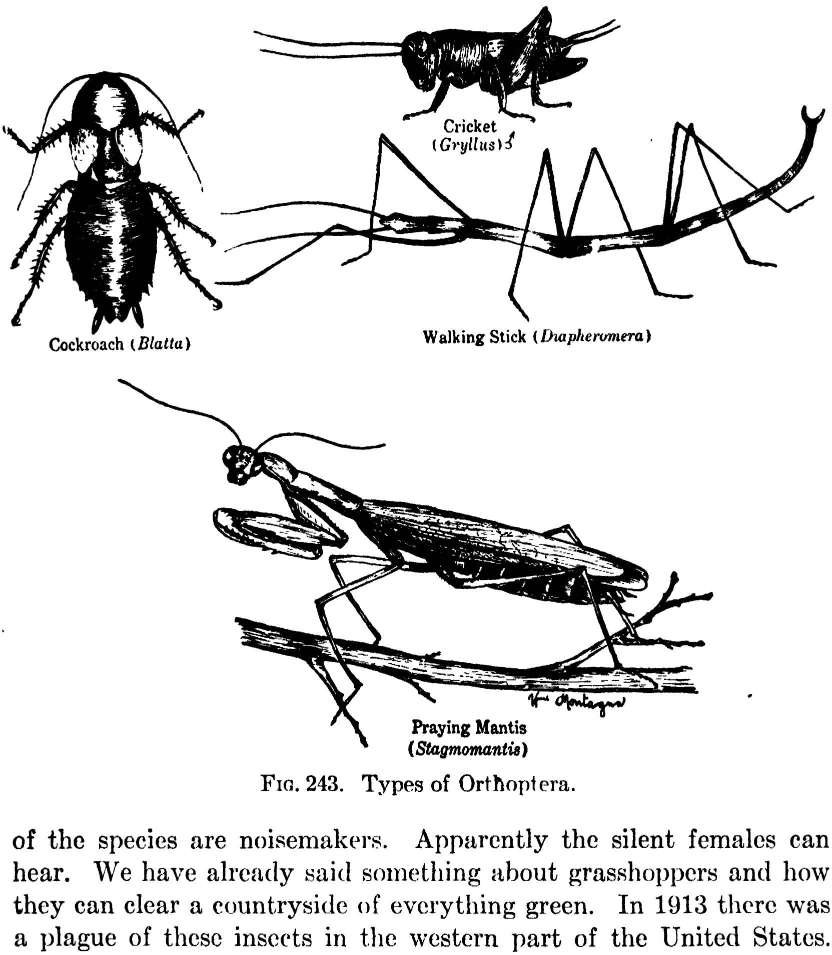


FIG. 243. Types of Orthoptera.

of the species are noisemakers. Apparently the silent females can hear. We have already said something about grasshoppers and how they can clear a countryside of everything green. In 1913 there was a plague of these insects in the western part of the United States. They were so numerous that railroad trains were stopped because the rails became slippery with the crushed bodies of so many insects. Grass on an area of more than 500 square miles was destroyed in this plague. Roaches are running insects which prefer the warm indoors. They are fond of foods, and will chew at woolen goods, leather, and anything starchy. They frequent all sorts of filthy and dusty places and may carry disease germs. They ruin the food they

do not eat by perfuming it with their disagreeable roachy odor. Crickets do not bother us much unless their cheerful chirping becomes too monotonous. Walking-sticks injure trees by eating the leaves. They have a curious appearance resembling the twigs of a tree. The female drops her eggs from the trees to the ground, and there parental care ceases. The praying mantis is a curious orthopteran that holds up the body and the front legs as though in a reverent attitude. However, this attitude is its proper posture for catching and crushing other insects.

ORDER COLEOPTERA (*koleos*—sheath; *pteron*—wing). Coleoptera is the largest order of Insecta, with over 175,000 species. In fact, two-fifths of all kinds of known insects are beetles. Beetles are extremely important, for they feed on practically all kinds of plants, stored food, and other materials. They are readily recognized by their horny, non-veined forewings (elytra), which serve as shields or sheaths to cover the membranous hindwings, hence the name Coleoptera. The mouth parts are of the chewing type like those of the Orthoptera. The Coleoptera have a complete metamorphosis, and the larvas are known as grubs and borers. (See Plate VIII.)

A number of beetles are very injurious. The potato beetles, erroneously called "potato bugs," came from Mexico and then spread each and west until they are now widely distributed. Nor should we overlook another Mexican immigrant, the Mexican bean beetle, whose insatiable appetite for green beans and bean plants has caused many amateur gardeners to forsake bean culture. Volumes could be written about the depredations of various beetles, but we shall merely list a few more. The larvas of pea and bean weevils bore through and ruin peas and beans. The cotton boll weevils have caused cotton interests in the United States a loss of $200,000,000–$300,000,000 per year. The larvas of the locust borer, the apple-tree borer, and the sugar-maple borer do their share of damage. It is estimated that bark beetles annually destroy trees worth $100,000,000. One of the best known of the destructive beetles is the Japanese beetle which landed on our shores about 1916, in New Jersey. From here it has spread to many parts of the United States. Some areas are more infested than others. These beetles eat both foliage and fruit, and their larvas (grubs) may injure the roots of plants by feeding on them.

But not all beetles are so unfriendly. Some are really beneficial and extremely interesting, among them being the carnivorous tiger beetles and certain ground beetles which spend most of the time busily hunting other insects. Scavenger beetles eat or bury decaying

matter. The "tumblebug," really one of the scarab beetles, lays its egg in a ball of dung and then buries it. The young larva feeds on the dung that the provident parent has provided. We should not fail to mention the ladybird beetles, many of which, both as larva and adult, feed on plant lice and scale insects. Dead, dried, and pulverized blister beetles are applied by physicians in plasters to raise blisters on the skin. Fireflies are not flies but beetles, and the females are wingless (glowworms). Junebugs are really not bugs; they are beetles.

ORDER LEPIDOPTERA (*lepis*—scale; *peteron*). Lepidoptera is a very large order, including some of the most destructive as well as the most beautiful insects such as moths, butterflies, and skippers. They have four membranous wings which are shingled over with scales, hence the name Lepidoptera. In fact, scales cover most of the body and readily rub off on the fingers in the form of dust, hence the common name "miller" is applied to some of these insects, especially the moths. The scales are of various shapes and contain the pigment responsible for the beautiful colors of moths and butterflies. The surface of the scales is creased with fine ridges or striae, as many as 35,000 to the inch, through which the light rays are diffracted. In some Lepidoptera this diffraction produces a beautiful iridescence.

Lepidoptera have highly specialized mouth parts adapted for sucking. Adult moths and butterflies feed mostly on nectar, which is hidden away at the bottom of the corolla of the flowers. Along the sides of the mouth are a pair of hairy or scaly palps, between which arises a slender tube, called a **proboscis,** used for siphoning the liquid food of the moth or butterfly. Usually the length of the proboscis is about the same as the depth of the corolla. Some of the tubes may reach a length of ten inches and when not in use are coiled up like a watchspring. Flower visitation by moths and butterflies assists in cross-pollination.

To the average observer butterflies and moths are indistinguishable. (See Plate IX.) However, several differences, not all infallible, serve to separate the two subgroups. The antennas of butterflies are knobbed, but those of moths are feathery or hairlike. Butterflies usually fly by day and moths by night. When resting, butterflies usually hold their wings in a vertical position; moths hold theirs horizontally or spread out.

Lepidoptera have a complete metamorphosis in which the larval or caterpillar stage is the most destructive. The white butterfly with black spots on the wings, a very common form, is called the cabbage

butterfly because its green larvas "riddle" cabbage leaves. Other interesting butterflies are the swallowtails, the mourning-cloak, and the monarch. Larvas of moths are the most destructive Lepidoptera. We need only to mention the tent-caterpillars and the web-worms which eat the leaves of shrubs and trees, the coddling moth whose larvas make such interesting and ruinous tracings in the apple, and the army worm which "marches" in countless numbers from field to field to destroy the green vegetation in its path. The brown-tailed moth, introduced into New England, not only is a pest on shade trees but also its hairs, shed during molting, are very irritating to the skin of certain people. The gypsy moth, accidentally introduced from Europe, has caused serious havoc with all types of trees. It is a real menace to our forests. The clothing moth causes untold damage to wearing apparel and other fabrics. The European corn borer is responsible for heavy losses in the corn crop of certain regions.

However, there are some helpful Lepidoptera. For example, the silkworm moth was domesticated in China many centuries before Christ. The larvas at the age of forty days spin cocoons of a single silken thread more than 1,000 feet long. Man then kills the larvas with heat and unwinds the thread for his own use.

ORDER DIPTERA (*dis*—twice; *pteron*). The Diptera are the flies, mosquitoes, gnats, the midges (Fig. 244). True to their name, they

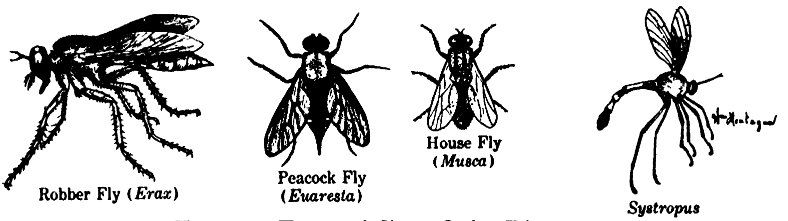


FIG. 244. Types of flies. Order Diptera.

have only two wings, the forewings, the hindwings being reduced to a pair of short, slender threads with knobs on the end. These threads, called **halteres** or **balancers,** may be organs of equilibrium. The front wings are small, gauzy, and adapted for very swift flight. The mouth parts are of the piercing-sucking type. Many Diptera feed on nectar and pollen; others on decaying flesh; some on blood; and still others dissolve and then suck up solid substances, as the housefly sucks up the icing of a cake.

The Diptera have a complete metamorphosis. Many larval flies are known as maggots and are found in decaying animal or vege-

table matter. Some larvas, such as those of the botfly, dwell in and feast on the living flesh of various animals. The larvas of certain gallflies feed on living plants. Some of the flies are viviparous, and in rare instances the larvas reproduce young. This production of young by animals sexually mature but in other respects immature, such as larvas, is called **paedogenesis** (*pais*—child; *genesis*—descent).

Horseflies are pests of horses and cattle. Here the "female of the species is more deadly than the male," for she sucks blood and he lives on nectar. Botflies cause great losses in domestic cattle. The female botfly fastens her eggs to the hair on the legs or shoulders of a cow or horse. When the host licks them off, they hatch. The young larvas are swallowed by the host and live in the walls of its stomach until in the pupa stage they are voided with the feces. Oxwarble, whose larvas live under the skin, alone causes an annual damage estimated at $100,000,000, by boring through and ruining the hides of cattle. The Hessian fly, the insect most destructive to wheat, causes an annual damage estimated at $100,000,000. It feeds on the stems, weakening them and causing them to ripen prematurely or even to break over so that maturation of the grain is prevented or reduced. The apple maggot, the larval stage of a dipteran, bores through the pulp in all directions. The tachina flies are among the beneficial Diptera. They lay their eggs in grasshoppers and various caterpillars. When the egg hatches, the larva feeds on the host in which the egg was laid. Robber flies feed on other insects.

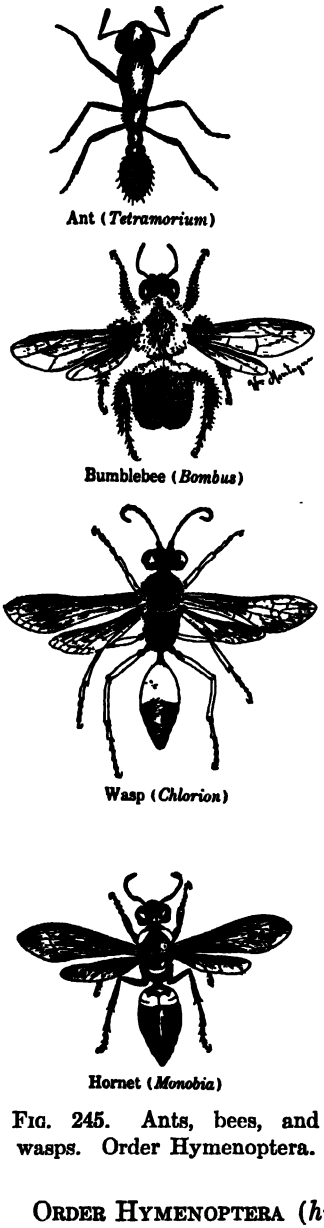


FIG. 245. Ants, bees, and wasps. Order Hymenoptera.

ORDER HYMENOPTERA (*hymen*—skin; *pteron*). Most of us readily recognize three kinds of Hymenoptera—ants, bees, and wasps; but it

is very doubtful that we know some of the other members, such as the gall wasps, the parasitic wasps, and the sawflies. Hymenoptera should top the list of invertebrate orders, for they exhibit a high degree of social organization and complex behavior. Many bees, ants, and wasps exhibit parental care, daily bringing food to the larvas, cleaning the nests, and guarding them. Other Hymenoptera, such as the many solitary bees, wasps, and gall-making species, merely lay their eggs where food is abundant.

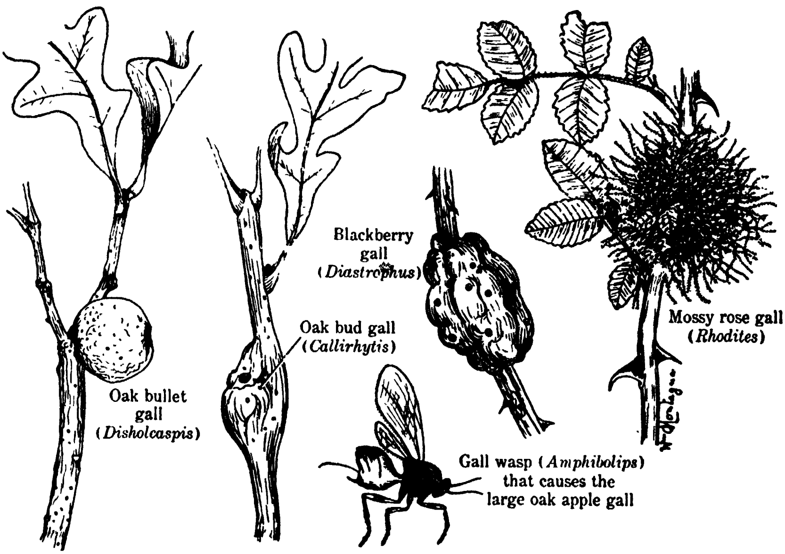


Fig. 246. Insect galls.

Hymenoptera have two pairs of small, scantily veined, membranous wings. Often the hindwings are fastened to the margin of the forewings by tiny hooks. The mouth parts vary from the chewing-lapping plan to the chewing type. Hymenoptera have a complete metamorphosis in their life history. Another peculiarity is that the ovipositor is often modified to form a sting; consequently only the females sting. As most of us know, the honeybee usually loses her sting in the wound because the nine or ten hooks on each dart which makes up the sting are pushed far into the wound. Some poison is added from the poison glands, making the wound more painful. Other Hymenoptera do not lose their sting and so can repeat the job. The sting with its poison is often used to stupefy other insects upon or in which eggs are laid, and then the victims are sealed up in the nest where they may serve as food for the young Hymenoptera.

The sawflies are really Hymenoptera. They are so named because the female has a long, sawlike ovipositor which she uses to make holes in plants in which she deposits her eggs. The eggs hatch into larvas which carry on serious depredations on currant bushes, willow trees,

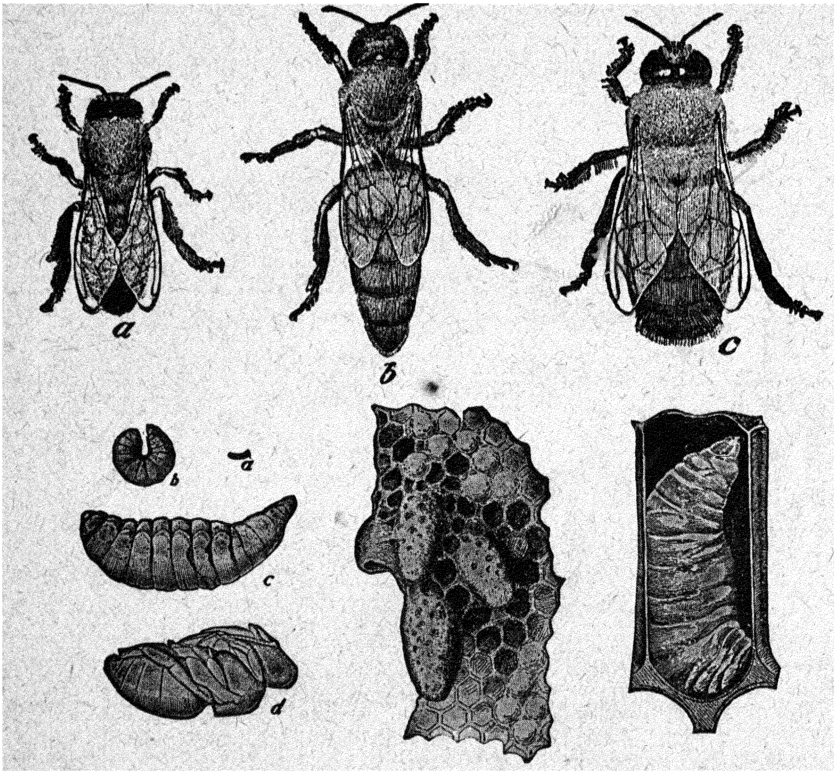


FIG. 247. Castes of the honeybee and some stages in their life history. *Above, a,* worker, or sexually immature female; *b,* queen, or sexually mature female; *c,* drone, or male. *Below, left,* egg (*a*), larval stages (*b* and *c*), and pupa (*d*); *center,* comb, showing some larger queen cells; *right,* side view of late larval stage within a cell. *From Curtis and Guthrie, "Textbook of General Zoology."* (*After White and Phillips, U. S. Department of Agriculture.*)

and other trees. Closely related are the gallflies, which puncture and lay their eggs in such plants as roses and oaks. The injury and the developing larvas cause the wounded part to produce excessive growths or galls which have various characteristic forms (Fig. 246). The larvas feed on this excessive wound tissue. Sometimes the true owners of the galls may entertain guests of the same superfamily and numerous parasites. One oak gall contained guests of ten different

species as well as forty-one species of parasites besides, of course, the gall maker! The chalcid "flies" are small Hymenoptera about one-fiftieth of an inch long. There are thousands of species of these flies, many of which are helpful in parasitizing the eggs, larvas, and pupas of harmful insects. They also make fig culture possible in this country.

Wasps are interesting Hymenoptera; some of them live in the ground, and others build nests of wood or mud. Many wasps make

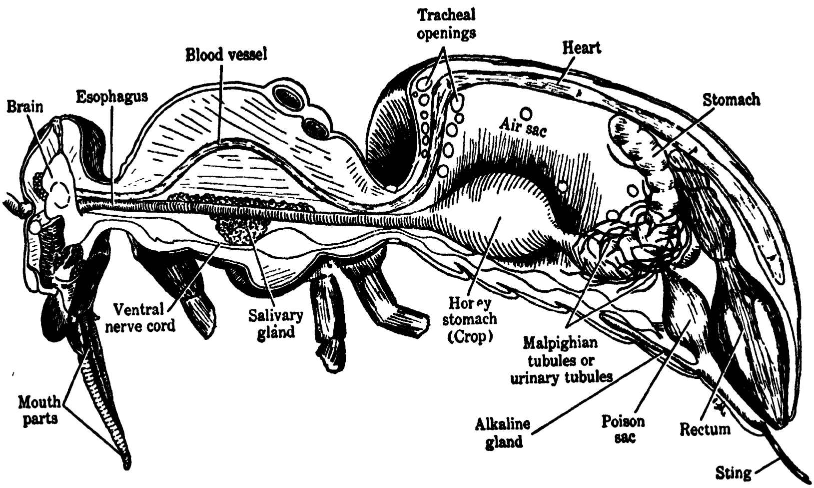


FIG. 248. Anatomy of the honeybee (worker).

nests by excavating burrows in the ground. They lay their eggs and then provision the nest with paralyzed spiders, caterpillars, and other insects on which they lay their eggs. Some wasps often capture insects which are too large for them to transport by flying to the nest. They have to push and drag the prey over the ground. The paralyzed hosts are sealed in the nest, and when the eggs hatch the young larval wasps have a plentiful food supply.

The honeybee is a social insect. In other words, a number of bees live together in a social group where there are different castes and division of labor (Fig. 247). In a hive of bees we find a queen whose job is to lay eggs. The workers, which are sterile females, do a number of different jobs in the community. They gather nectar and pollen from the flowers. The nectar mixed with saliva is carried home in the honey sac, a modification of the crop (Fig. 248). The pollen is carried on brushlike structures (pollen baskets) on the legs. The nectar mixture is regurgitated into the hexagonal cells in the

waxy honeycomb, where, by the aid of the fanning wings of other workers, it is evaporated to the syrupy honey consistency. The cell is then sealed up. These cells were made from wax produced by wax glands. The wax is carefully chewed and kneaded by the mandibles before it is placed in the comb. It has been estimated that between 40,000 and 80,000 trips, or more, are necessary to collect enough nectar to make a pound of honey. If a single bee did this it would travel a distance equal to twice around the world.

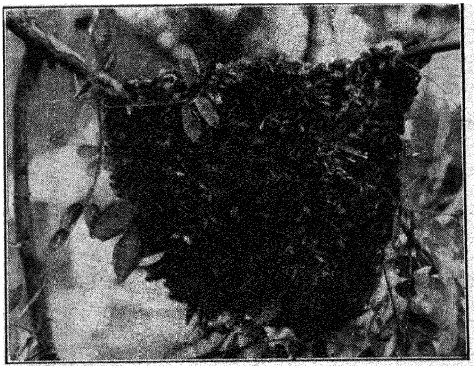


FIG. 249. A swarm of bees. *Photograph by Frank C. Pellet.*

Some workers create currents of air in the hive to aid in condensation of the honey; others clean the hive; and still others care for the young bees. The males do no other work than to fertilize the virgin queen in her nuptial flight. Bees "swarm" when a queen leaves the parent hive and takes with her many of the workers and drones to found a new community (Fig. 249). Bees produce annually more than $20,500,000 worth of honey and wax. In addition they make an invaluable contribution to plant pollination. Few people realize that in addition to the social bees there are a number of species of solitary bees.

Ants, widely distributed over the world, may be the most abundant insects from the standpoint of numbers. Ants feed on a variety of foods. They may eat dead or helpless insects or keep aphids as slaves and feed on their sweet excretion, called honeydew. They also find stored sweet foods quite satisfactory. Socially ants are even further developed than bees (Fig. 250). As in the bee colony, the queen founds the colony and the male's function is to fertilize the queen. All the workers are sterile females. Among the workers may be found large and small individuals, soldiers, gardeners, and attendants for queen. In the ant colony the queen produces eggs and larvas,

often numbering thousands, which are cared for by the workers. The queen's sole task is egg laying.

The male and female ants are winged and mate while in flight. After the nuptial flight the males die; the queen breaks off her wings and seeks out a cavity or makes one in the ground. She then closes

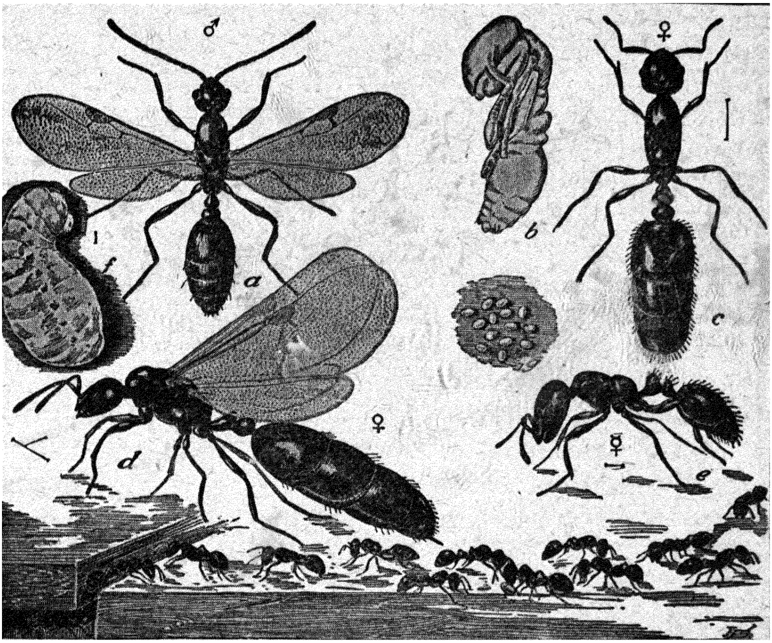


Fig. 250. Castes of the little black ant *Monomorium*. Order Hymenoptera. *a*, male; *b*, pupa; *c*, wingless female; *d*, winged female; *e*, worker, or sexually immature female; *f*, larva; *g*, eggs; group of workers in line of march below. *From Sanderson and Peairs, "Insect Pests of Farm, Garden, and Orchard."* (*After Marlatt, U. S. Department of Agriculture.*)

the opening of the cavity and remains isolated for a period of days, weeks, or months. When the eggs in the ovary have matured they are fertilized by the spermatozoa she received from the male. The eggs are then laid. They soon hatch, and the queen takes care of the young by feeding them from her own saliva. After the young are mature they take over all the duties of the colony except egg laying.

Order Hemiptera (*hemi*—half; *pteron*—wing). The Hemiptera are the true bugs. They have piercing and sucking mouth parts which enable them to pierce both plants and animals and suck out the sap or blood. (See Plate X.) Some groups of these insects are without wings, but as a rule wings are present. The front wings have two

regions: the anterior portion is hard and horny, the posterior thin and transparent. Between the bases of the wings there is usually a characteristic triangular plate. This group includes a number of insects injurious to man. The chinchbug, one of the worst pests, feeds on small grains and corn. In the Mississippi valley, in a single season, it caused damage estimated at $100,000,000. These bugs are kept partially under control by a fungus disease. The tarnished plant bugs feed on more than fifty kinds of plants. They attack fruit trees in bud, flower buds, and the leaves of potatoes and beets. The bedbug, a blood sucker, belongs in this group.

However, we do have some friends in this group. There are the ambush bugs which hide in plant blossoms and capture insects as they visit the plant. Other bugs delight in a diet of bedbugs. The waterstriders are often seen scooting over the quiet surface of the water in some pond or sluggish stream, and associated with them are small, greenish black water boatmen. On the bottom of the pond there may be giant waterbugs two or three inches in length. All these are carnivorous and feed on other insects.

ORDER HOMOPTERA (*homos*—same; *pteron*). The mouth apparatus of this order is about the same as that in Hemiptera, but the beak is attached to the head differently. The wings may be lacking, but when present they are similar in texture throughout. (See Plate X.) When the insect is at rest the wings are usually held folded over the back, resembling the roof of a house. There is quite a difference in the appearance of the members of this order, which includes such extremes as the cicadas, the leaf hoppers and tree hoppers, plant lice, scale insects, and others.

The seventeen-year locust is really an interesting homopteran, a cicada. The female using her ovipositor gouges a series of grooves in the twig of a tree and lays her eggs in them. The twig dies. In about six weeks the eggs hatch; the nymphs fall to the ground and dig in to live seventeen years as nymphs. During this period they secure their food by sucking the juice from roots. After seventeen years of this secluded life, they leave the soil, crawl up on a plant, shed their last nymphal skin, and emerge as adult cicadas to make the summer air hideous with their rasping, discordant songs.

The leaf hoppers assume many bizarre forms. The adults cause most of the damage when they puncture the twigs of plants in laying their eggs. Another interesting group of the hoppers are the "spittle" insects, whose nymphs hide in a mass of froth on the grass or other plant in which they may be feeding.

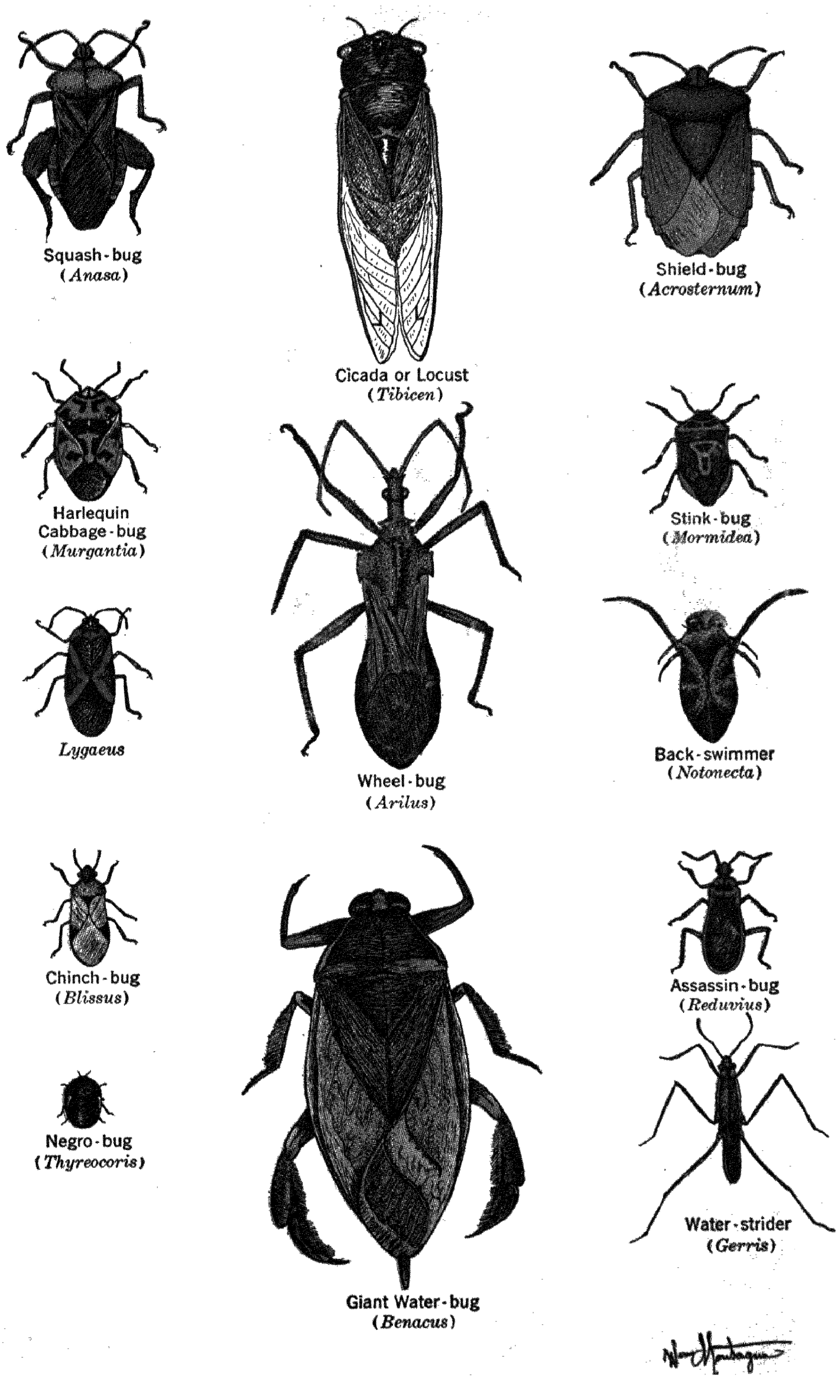


PLATE X. Types of Hemiptera.

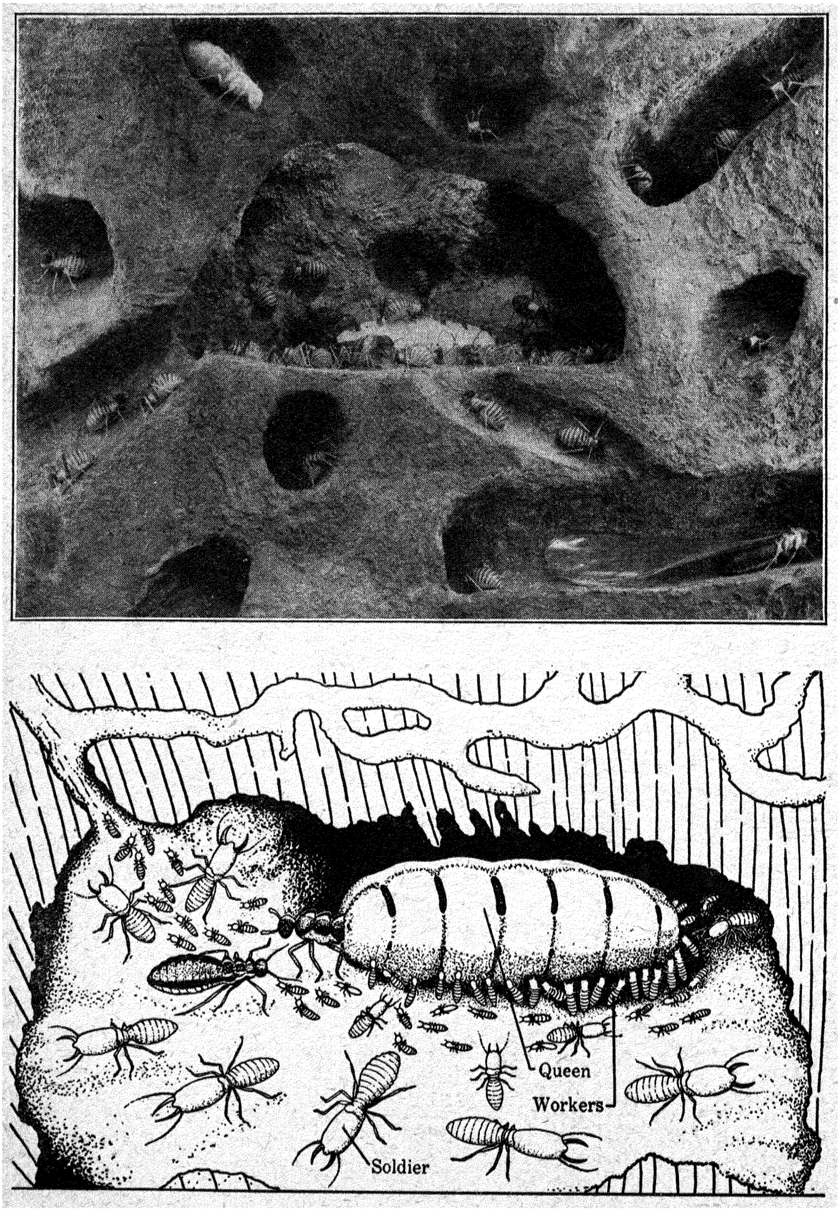


FIG. 252. Termites. *Above,* model of nest of termites and tunnels through the wood; *below,* drawing of various castes. *Photograph furnished by the Buffalo Museum of Science, Buffalo, New York.*

eyes, some of which have as many as 30,000 facets. They are carnivorous, feeding on smaller insects, both friend and foe from man's standpoint. The young nymphs live in water and destroy many mosquito larvas. The nymphs also form an important item of fish food (Fig. 251).

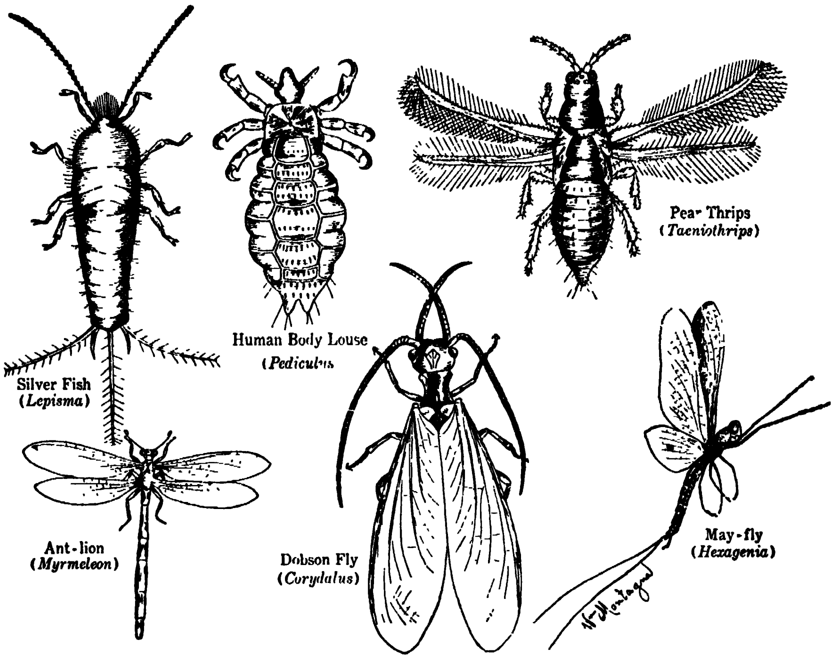


FIG. 253. Some common insects of various orders.

ORDER ISOPTERA (*isos*—equal; *pteron*). The Isoptera are the so-called white ants or termites. They are often found in decaying trees or in the woodwork and supports of dwellings, where they do considerable damage. They are strongly negative to light and will build covered runways of soil mixed with secretions to get from one working place to another. They resemble ants in their social organization, although they have an even more complicated caste system. There are kings, queens, soldiers, policemen, and workers of several types. In fact, in some colonies there are as many as eight different castes. The queen tears off her wings after mating and becomes greatly enlarged, sometimes almost a thousand times as large as her consort. Her sole function is to produce eggs. She then becomes so helpless that she requires the services of nurses to feed her and keep her clean (Fig. 252).

Other orders of insects are:

ORDER THYSANURA (*thysanos*—fringe; *oura*—tail). Springtails and silver fish which destroy starchy materials such as book bindings.

ORDER EPHEMERIDA (*ephemeros*—lasting but a day). Adult mayflies live only to mate, lay their eggs, and die.

ORDER PLECOPTERA (*plekein*—to twine; *pteron*—wing). Stoneflies, whose nymphs make excellent fish food.

ORDER CORRODENTIA (*corrodens*—gnawing). Book and bark lice

ORDER MALLOPHAGA (*mallos*—a lock of wool; *phagein*—to eat). Biting bird lice which eat hair, feathers, and epidermal scales. They are not fatal but very annoying to chickens and other birds.

ORDER THYSANOPTERA (*thysanos*—fringe; *pteron*). Thrips, which are often destructive to citrus fruits.

ORDER NEUROPTERA (*neuron*—nerve; *pteron*). Ant lions, which are carnivorous. Aphis lions live on aphids. Larval ant lions, "doodlebugs," hide in their sandy pits where they capture and suck the blood of ants which happen to fall in.

ORDER MEGALOPTERA (*megas*—large; *pteron*). Dobson flies, whose larvas, familiar to many as the "hellgramites," are used for fish bait.

ORDER MECOPTERA (*mekos*—length; *pteron*). Scorpion flies.

ORDER TRICHOPTERA (*trichos*—hair; *pteron*). Caddice flies, whose aquatic larvas build a case of bits of leaves, grass, or sand for protection.

ORDER SIPHONAPTERA (*siphon*—tube; *a*—without; *pteron*). Degenerate fleas, which have lost their wings and have sucking mouth parts. Their bodies are laterally flattened, and the legs are adapted for jumping. They are found in the fur and feathers of animals.

INSECTS AND DISEASE

Contrary to oft-repeated accusations there has been no clear case against the bedbug as an important **vector** (*vectum*—borne) in disease. Excessive biting by the bugs may cause anemia, nervousness, and "influenzalike" symptoms. The sucking lice (Anoplura) are most important as disease vectors; they transmit typhus fever and trench fever, two diseases that may assume epidemic proportions in wartimes and famine. Lice do not transmit the disease by biting but only by contamination with their excreta or from their crushed bodies. The infectious parasite *Rickettsia* may live for several weeks in the dried dead bodies and feces of the lice. Relapsing fever, caused by spirochetes, is transmitted only by broken and crushed lice. Lice *may* also transmit bubonic plague and certain other bacterial diseases. The remedy is cleanliness and proper sanitation for all the people in a community. Lice and typhus are the companions of war, famine, poverty, and personal neglect.

On the basis of their hosts, fleas fall into three groups: human fleas cat and dog fleas, and mouse and rat fleas (Fig. 254). Most fleas are neither strictly host parasites, that is, parasites which live exclusively

on the host, nor nest parasites, like the bedbugs. The human flea lays its eggs in the dust and debris in the cracks of the floor, under the carpets, in the crevices of the wallpaper, or like places. The young larvas feed upon such material as hairs, mouse excreta, and excrement of adult fleas.

Fleas are blood-sucking parasites. They transmit such diseases as bubonic plague and certain forms of typhus. They are important vectors of **tularemia.** At the present time, this disease is found mostly

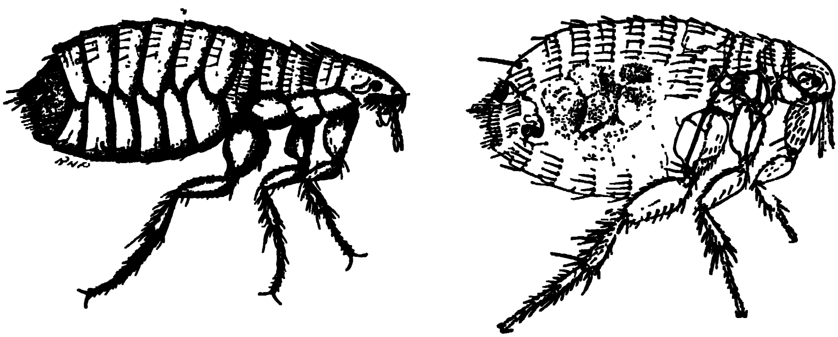


FIG. 254. *Left,* a dog flea (*Ctenocephalus canis*); *right,* Indian rat flea (*Xenopsylla cheopis*), a vector of bubonic plague. *Dog flea from Peairs, "Insect Pests of Farm, Garden, and Orchard," published by John Wiley & Sons. Rat flea from Thomas T. Mackie et al., "Manual of Tropical Medicine," W. B. Saunders, 1945.*

in tropical countries such as India, where each year over one-half million people die from it. The organism is found in the blood of rodents and is transmitted by the rat flea (*Xenopsylla cheopis*) which has fed on the blood of an infected animal. Fleas also are carriers of typhus, a disease found in the blood of rodents. Apparently it is transmitted to man from the feces and crushed bodies of the fleas. Fleas have also been suspected of being the carriers of relapsing fever. The remedy for fleas is to clean thoroughly the premises and sprinkle the flooring or ground with a good insecticide.

The flies, midges, and mosquitoes, Order Diptera, are more important than all the other arthropods as disease vectors. The sandflies (*Phlebotomus*) are small midges which can easily penetrate the meshes of ordinary netting. Some of the species feed exclusively on blood and are of great importance as transmitters of various types of leishmaniasis. They also transmit a virus disease known as three-day fever. In Peru they have been shown to be the vectors of Oroya fever. In the guts of these insects have been found the parasites causing

Oriental sore, espundia, and kala-azar. The most important mode of transmission involves the crushing of the bodies of the vectors on the skin. There is some evidence that they may transmit disease by biting. The best protection against sandflies is an electric fan and oil sprays. The midges have been accused of transmitting a form of dermal leishmaniasis, and they also serve as intermediate hosts of two human filarial roundworm parasites.

The horseflies or tabanids are also blood suckers. Some of them cause trypanosome diseases of domestic animals such as surra in horses, camels, and cattle. They may even occasionally transmit the trypanosome of human sleeping sickness. Certain stable flies may transmit anthrax. Other species of these flies (*Chrysops*) have been found to be transmitters of tularemia and the roundworm *Loa loa*. The only means of fighting these flies is by repellents.

Tsetse flies have already been mentioned as the vectors of sleeping sickness, a trypanosome disease. They are limited in their range, however, to the middle portion of the African continent. It has been suggested that sleeping sickness could be controlled by the elimination of certain African game animals which harbor the parasites in their blood. However, this would be a gigantic task, and evidence would seem to indicate that the results would not justify such a course.

The eye flies (*Oscinidae*) in Florida may cause "pink eye." Other species in the West Indies may be responsible for the majority of the cases of yaws, because the spirochetes of yaws have been found motile in the pharynx and digestive tracts of certain of these species. Infection occurs when the flies regurgitate fluid from their digestive tract after feeding.

Mosquitoes are probably the worst of all insect pests. This is one pest which is more abundant in the cold northern countries than in the tropics. However, the northern mosquitoes are not disease carriers. Four human diseases are transmitted by mosquitoes exclusively: malaria, yellow fever, dengue, and filariasis. The eggs of the South American fly, which in the larval stage affects man, are also carried by mosquitoes. Contrary to popular opinion, mosquitoes feed to a large extent on plant juices, honey, and other products. All the males are vegetarians; the females are the blood suckers. The genus *Anopheles,* which is a vector of the malarial parasite, is widely distributed, not only in the northern sections of the world but in the jungles and forests of the tropics as well. Most *Anopheles* mosquitoes feed in the evening; therefore one is not so likely to receive a bite and consequent infection during the day.

Yellow fever is transmitted by a mosquito called *Aëdes aegypti.* This mosquito lives in and around houses; in fact, it seldom leaves the room of a house except to find a breeding place, which may be a rain barrel, water-filled tin cans, sagging roof gutters, flower vases, in fact, any small body of water. The yellow-fever mosquito is widely distributed, and, since it stows away quite readily in clothing, one can readily appreciate how easily these insects with their disease-producing guests may be scattered throughout the world.

Mosquito control may utilize the following methods: use of repellents and protective clothing; elimination and exclusion of mosquitoes from dwellings; and, finally, the destruction of breeding places and larvas. In mosquito-infected areas all pools of water should be eliminated or the surface covered with oil, which kills the larvas. Certain species of fish that feed on mosquito larvas have been found useful.

Myiasis is a term used to describe a human infection by fly maggots. The so-called muscoid flies are most frequently involved in myiasis. The botfly larvas are entirely parasitic in the larval stage. Fly myiasis may be of four types: the larvas may live outside the body and suck blood by puncturing the skin; the larvas may burrow into the skin and develop under it; eggs or young larvas may infect the wounds or the natural cavities of the body such as the nose or ear; and some larvas live in or pass through the intestine or urinary passages.

The Congo floor maggot (*Aucheromyia*) lies buried in the dust under sleeping mats during the day and comes out at night to suck blood from sleepers. The larvas of two species of flies live under the skin of animals where they cause nodules or boil-like lesions frequently called warbles. They attack cattle and other domestic animals more often than man. A domestic animal may become infested with thousands of the larvas; the hides of animals are often so riddled by their perforations as to be worthless. Man often attempts to remove the maggot, but unless he is careful a serious and even fatal secondary infection may occur.

The African skin maggot is the larva of a yellowish brown fly found in tropical Africa. The eggs are laid on exposed clothing or dry sand about which there may be some body odor. When stimulated by heat, as when one puts on a garment, the activated larva soon buries itself under the surface of the skin. The lesions that are produced enlarge, and in heavy infections death may result.

As was pointed out before, the larvas of certain flies attack wounds. Even a scratch may afford the stimulus or point of attack for myiasis.

These maggots may also attack the natural cavities of the body. Severe infections of man may lead to death. One member of the screw-worm family found in southeastern Europe breeds in open wounds. The larvas need to be removed as soon as possible, and the wounds made by their removal must be carefully cared for by antiseptic methods.

In this very brief presentation of the insect parasites, it has been possible to mention only a small fraction of the different species of animals involved. Further, very little has been said of the losses to man of his domestic animals through the attacks of these parasites.

Battling the Insects

We have just seen that insects are injurious in various ways. Some ruin plants by chewing; others content themselves by sticking in their beaks and sucking the sap. Some work into the inside of plants and tunnel about through the tissues. Even the heartwood of large trees is often tunneled and ruined by insects. No part of a plant is immune from the insects; root, stem, leaves, and fruit, are all liable to attack. The damage done directly by insects is bad enough, but, in addition, insects carry the spores of various plant diseases which find entrance into the plant through the wounds they make.

Man fights the insects in various ways. Sometimes he resorts to chemical warfare and sprays the herbs, trees, and shrubs. When insects eat some of the sprayed plant material the poison sets up an inflammation in their stomachs, and the insects die. Some sprays, known as contact poisons, enter through the spiracles and corrode the tissues, thus cutting off the oxygen supply. Oils, soaps, nicotine, and sulphur are much used as contact poisons, which must touch the insect to insure a kill. Within a closed space, such as a house, granary, or museum cases, fumigants are sometimes employed to kill insects. The airplane has been utilized for dusting large areas of crops.

A new insecticide, DDT, promises to revolutionize methods of insect control. It has already been used extensively to help control malaria and typhus. It can be sprayed on walls or even mixed in certain interior paints and finishes, where it retains its potency over a long period of time. However, if too great a quantity of DDT is swallowed or absorbed through the skin, it may prove poisonous to man or other animals.

Man uses mechanical means as well as chemical. He often picks the insects or the larvas from his plants or wields a swatter effectively. Ingenious traps and collecting machines have been developed. One

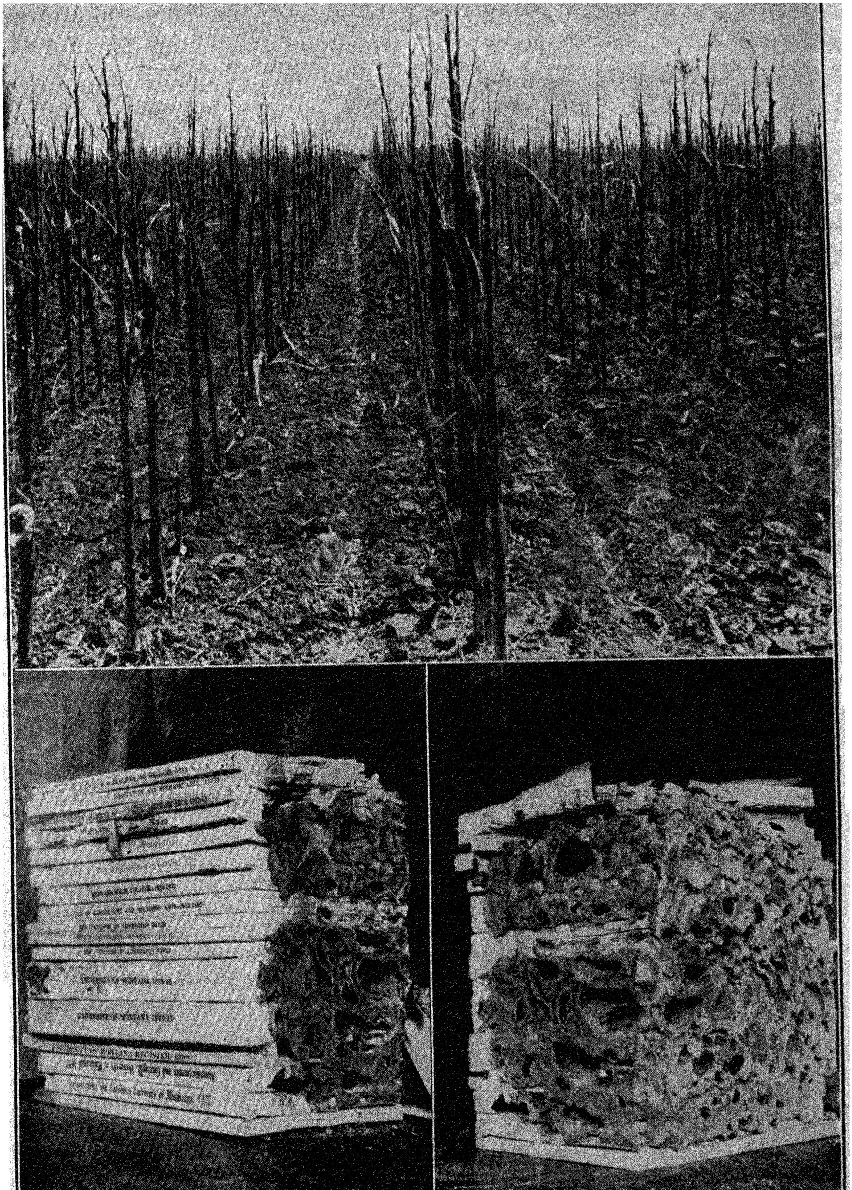


FIG. 255. Destruction caused by insects. *Above*, grasshopper damage in the Chikaskia River Valley, Oklahoma. *Below*, damage done to books by termites. *Upper photographs furnished by Soil Conservation Service, U. S. Department of Agriculture. Lower photographs furnished by J. W. Ward, by permission of the General Biological Supply House.*

of them, called a hopperdozer, is a trough-shaped affair with a high back screen (Fig. 256). It is drawn by horses over a field, and the aroused insects, mostly grasshoppers, as they fly up, hit the back of the screen and fall into the trough. They may then be killed by a

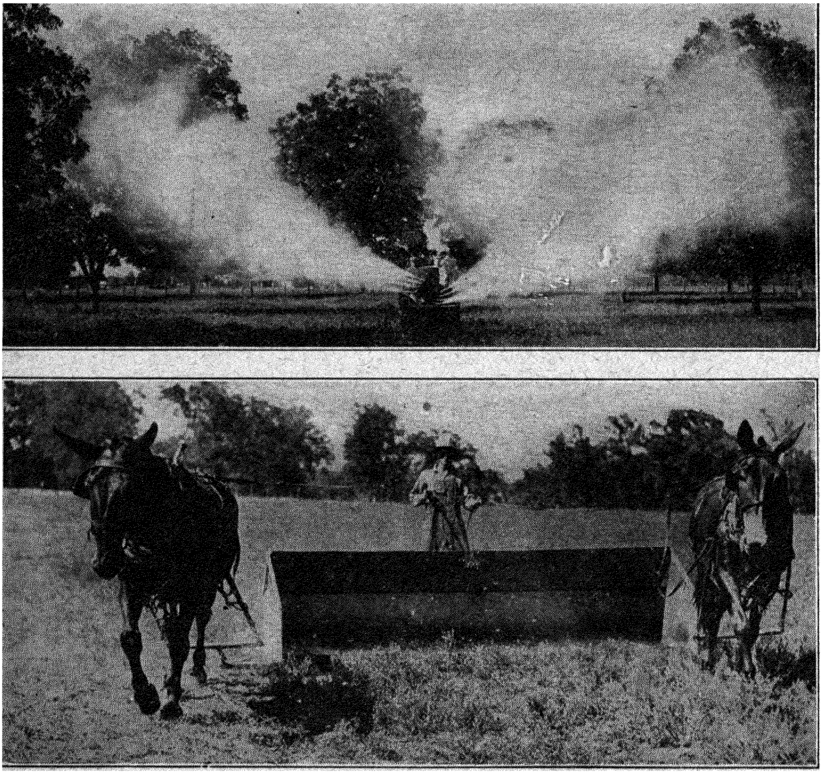


FIG. 256. Fighting insects. *Above,* dusting trees; *below,* hopperdozer. As the 12-foot sled is dragged over the alfalfa field, the insects try to leap over it, hit the backboard, and drop into a tray containing an oil mixture that kills them. *Upper photograph furnished by Root Manufacturing Company; lower photograph furnished by Acme Photo, New York.*

kerosene solution, or allowed to accumulate. They may be sacked, dried, ground, and used for hog or chicken feed. From 4 to 8 bushels per acre has been collected with these machines.

Some insect pests can be controlled by crop rotation and by varying the time of planting and harvesting. All soil should be kept as free as possible from weeds and such crop residues as corn stalks and wheat stubbles. Pruning or thinning trees and shrubbery often helps to control insects.

Efforts have been made to kill certain insects by inoculating some captured individuals with a fatal fungus or bacterial disease and then releasing them to spread the disease. This type of control is meeting with fair success against the Japanese beetle. Often predatory insects are introduced to prey upon injurious forms. At one time the cottony cushion scale, which was accidentally introduced from Australia and New Zealand, threatened to kill all the orange trees in California. Five hundred lady beetles were brought from Australia and released. Within a comparatively short period, the lady beetles brought the scale insects under control throughout the entire state. This is a good example of what happens when the relationships in a community of living organisms are destroyed and then restored. Parasitic insects have been most useful agents in insect control. We must not forget that there are many other insectivorous insects, such as wasps, certain diptera, dragonflies, various beetles, and bugs. Spiders also are man's partners in these wars. We have already mentioned the services of the Amphibia, certain snakes, lizards, and the birds. We cannot emphasize too strongly the need for bird protection as well as assistance in building up bird refuges, breeding places, and the like.

Class Arachnida (*arachne*—spider). The animals of this class are familiar to us as spiders, but there are others as well, such as the scorpions, daddy longlegs or harvest men, mites, and ticks. The head and thorax are fused to form a **cephalothorax,** and the abdomen is unsegmented. Both the cephalothorax and abdomen are covered with chitin. The arachnids have neither antennas nor mandibles. In front of the mouth arachnids have a pair of appendages, in the form of either pincers or sharp claws (Fig. 257), called **cheliceras.** Behind the mouth and the cheliceras is a pair of appendages called **pedipalps,** which in spiders are sensory in function but in scorpions are used for seizing prey. Arachnids have four pairs of walking legs and no compound eyes.

The spiders usually have eight simple eyes. On the abdomen of most spiders there are no appendages except the three pairs of tiny little spinning glands called **spinnerets,** which secrete a sticky fluid that hardens, on exposure to the air, into relatively tough, flexible threads often arranged in beautifully designed webs. The spider waits in the web until some insect, probably a fly or grasshopper, becomes slightly entangled. It then pierces the prey with the pedipalps and injects a poison. If the captured animal is too large the spider weaves a silken net to hold the struggling victim. The spider sucks the juice from its victim, after which it throws the shrunken body out of the web. The food is sucked into the stomach and thence into the

intestine, whose surface is increased by a number of pouches or caeca, The caeca enable the spider to tide over long periods between meals. The food is absorbed into and distributed by the blood, which is driven by the tubular heart through the vessels and hemocoels. This colorless fluid is a carrier of oxygen and carbon dioxide also. The exchange of gases takes place in the special breathing organs called "book lungs," tracheae, or both. The urinary wastes are eliminated by the Malpighian tubules as in the insects.

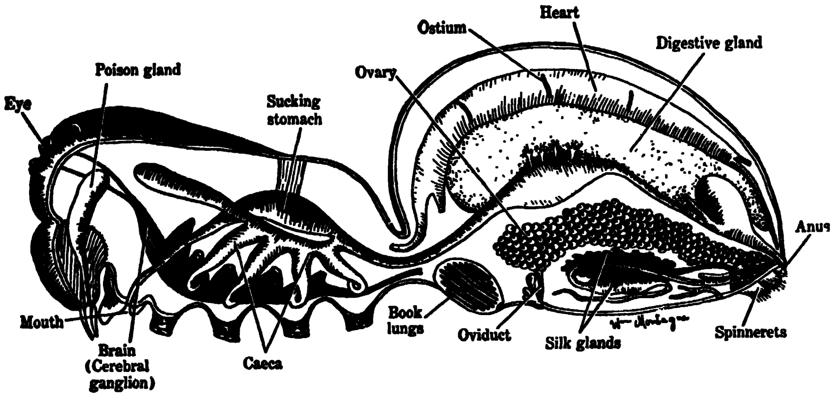


FIG. 257. Diagram of the internal anatomy of the spider. *Modified from various sources.*

Spiders are of separate sexes. The female is often much larger than the male, who courts her in her web by striking fantastic poses and by doing a dance. If he is accepted he may be eaten, even before the marriage, by the female. The eggs are laid in cocoons, which may be fastened to various objects or carried around by the spider. After some months the young come out of the cocoon and spin a strand of silk on which they are carried around by the wind to new homes, often many miles away. There are various types of weaving spiders, but not all spiders spin webs. Some merely run around; others are able to jump.

Spiders are very interesting and much-maligned animals. They are of positive value to man, for they feed almost entirely on insects. Most of them have poison glands, and their bite is fatal to many smaller animals but not to man as a rule. The spiders most to be feared by man belong to the genus *Latrodectus*. The bite of one species is dangerous to horses and camels. A few authentic cases of human death from spider bites are known, but generally the result is discomfort for a period of a few hours to ten days, followed by re-

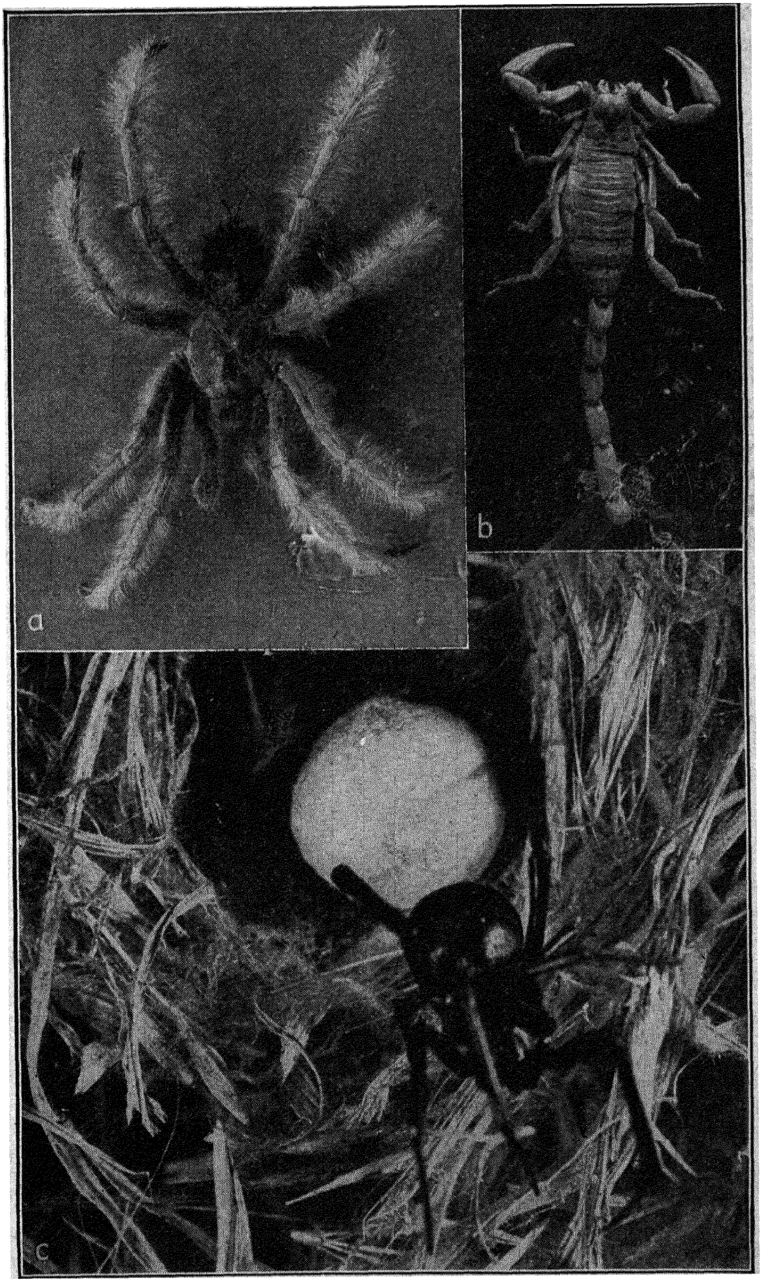


PLATE XI. Types of Arachnids. *a*, tarantula; *b*, scorpion; *c*, black widow spider. *Photographs a and b furnished by Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture; c furnished by Nature Magazine.*

covery. The species most dreaded in America is the black-widow spider, whose bite, although not so deadly as popularly believed, may cause intense agony, and rarely death.

Most of us have seen the daddy longlegs but have usually thought of them as insects. They are arachnids, and they use their eight slender elongated legs in chasing insects. Scorpions are found mostly in tropical countries. They are carnivorous and have on the tip of the abdomen a slender poisonous sting which they use in capturing their prey. The sting may be serious to man, sometimes resulting in death. Anti-scorpion serum has been found effective.

Most **mites** are round or oval in shape with head, thorax, and abdomen fused. When certain mites burrow beneath the skin, they cause itch, mange, and "scab" in man and other animals. The female makes a burrow in the epidermis and lays her eggs. The young hatch and in turn make burrows of their own. The infection may hang on for some time and become known as the "seven-year itch."

Ticks are transmitters of many diseases of man and domestic animals. They cause much sickness and death and enormous economic losses. All ticks are parasitic at some time in their lives. They suck the blood of the host.

Ticks have an interesting life history, which is more or less similar for all species. The eggs, and there may be as many as 10,000 from one female, are deposited on or near the surface of the ground. Here they develop into larvas, popularly known as "seed ticks," which climb up on a blade of grass from which they may attack their host and feed on his blood for several days. Then they drop off, undergo further development, and often attack the host again. After the second feast they again drop off and finally become mature ticks which must contact the final host.

Ticks are widely scattered over the world, and wherever they go they have the reputation for spreading disease. Members of one genus in the United States (*Dermacentor*) are credited with carrying spotted fever, tularemia, Colorado tick fever, "nine-mile fever," tick paralysis, and several viruses (Fig. 258).

In addition to carrying diseases, ticks themselves are dangerous to man. Wounds made by tick bites often become infected and result in rather extended sores and ulcers. In some domestic animals they have caused serious and even fatal anemia. Sometimes female ticks, attaching themselves to the back of the neck or the base of the skull and gorging on the blood of an individual, may cause paralysis. The

individual recovers in six to eight days unless the heart and respiration become affected. Sometimes paralysis of the heart and respiratory muscles ensues, followed by death.

The control and eradication of ticks present a difficult task. Clearing away the brush and burning over tick-infested lands are common control measures. Certain domestic animals are dipped in vats containing a fluid that kills the ticks. Certain rodents serve as reservoirs for many of the diseases carried by ticks. In Montana, for instance,

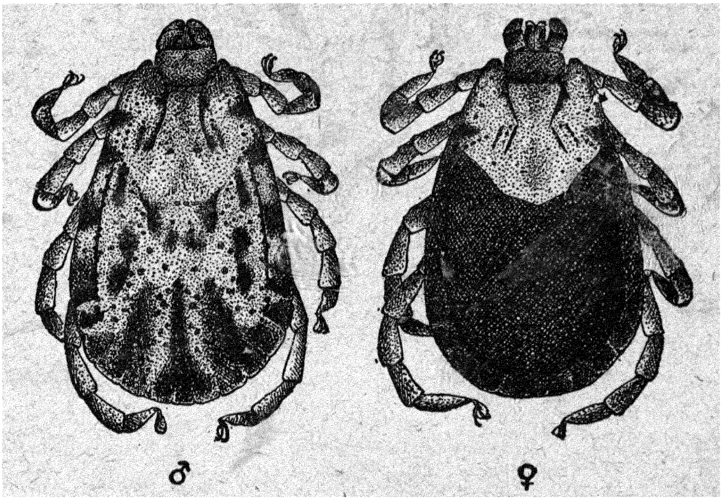


FIG. 258. Spotted fever tick. *From Chandler, "Introduction to Parasitology." By permission of Asa C. Chandler and of John Wiley & Sons.*

quite a campaign has been conducted for the elimination of ground squirrels, which are the hosts for immature ticks. Meadow mice and white-footed mice also serve as refuges for ticks in their immature stages.

Class Paleostracha. The only living representatives of the class are the king crabs (*Limulus*). They resemble so closely certain extinct arthropods that they have been called "living fossils." They are marine and live on sandy or muddy bottoms, where they feed on worms and mollusks. They have five pairs of typical arthropod appendages and a respiratory organ made up of flattened plates and known as a **gill book.** The animals are of little economic value.

Class Onychophora (*onychos*—claw; *phoros*). These are soft-bodied wormlike arthropods which are not very plentiful and do not occur in the United States. They feed on insects and spiders. They are of peculiar interest because, in addition to being arthropods, they have annelid characteristics; therefore they are often called mosaic animals.

PHYLUM ECHINODERMATA

(*echinos*—hedgehog; *derma*—skin)

This phylum numbers among its members the starfishes, sea urchins, sea cucumbers, and others, all of which live in the salt water.

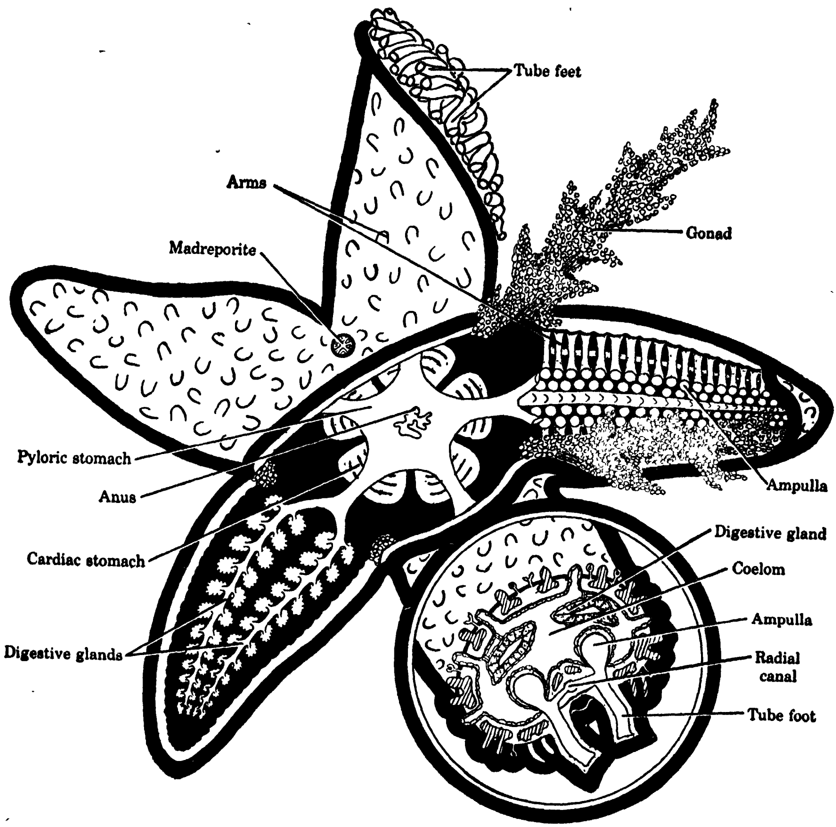


FIG. 259. Internal anatomy of the starfish.

Some echinoderms are found crawling slowly around in the shallow water along the shore or partially concealed in the crevices of the rocks. Others live in the deep parts of the ocean. Among them are the crinoids or sea lilies, most of which are attached.

Echinoderms begin life with bilateral symmetry but gradually change until in the adult they have **radial symmetry.** Most of them have an **endoskeleton** made up of plates of calcium carbonate, imbedded in the body wall. Many of the plates are equipped with

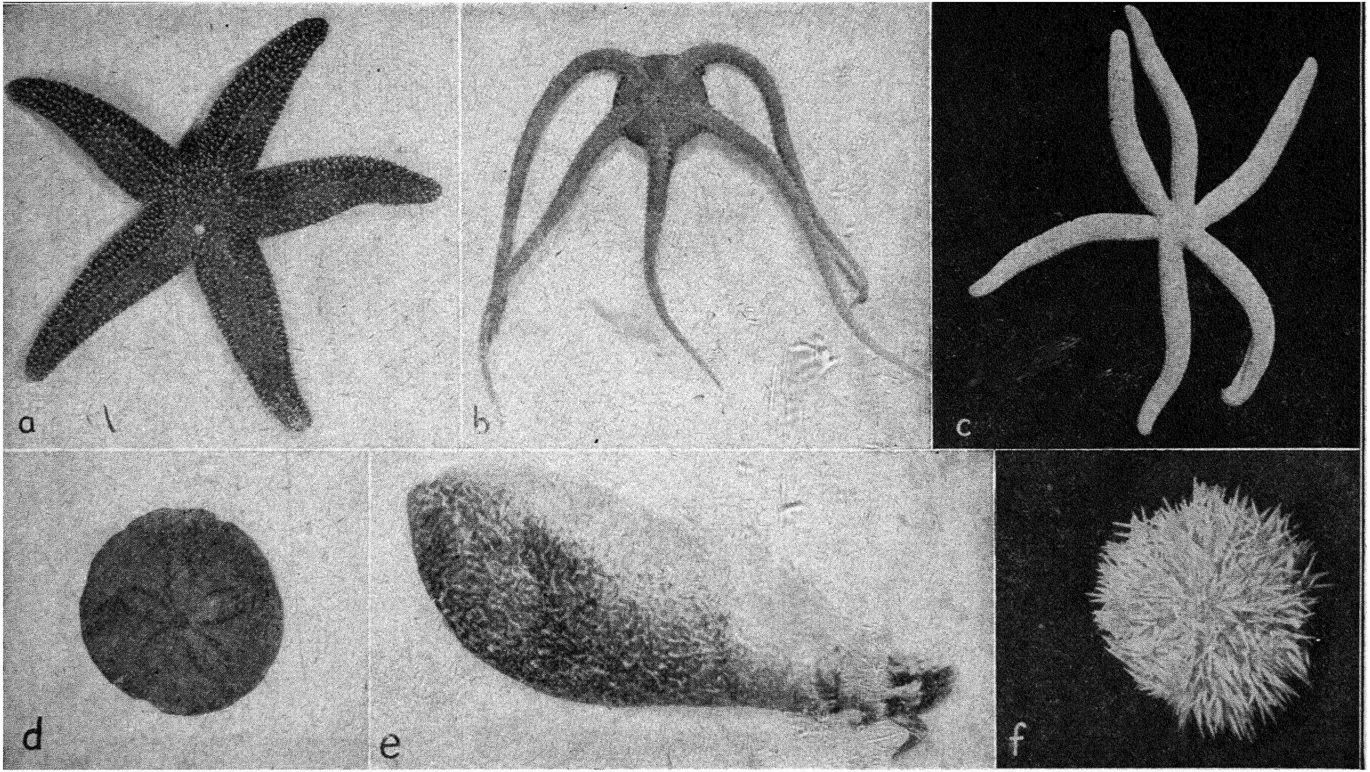


Plate XII. Types of Echinodermata. *a*, starfish (*Asterias*); *b*, serpent stars; *c*, starfish (*Echinaster*); *d*, sand dollar; *e*, sea cucumber; *f*, sea urchin. *Photographs a, b, c, d, and f, by Ervin Kalal; e, by David Huntsberger.*

spines, a condition which is responsible for the name of the phylum. Another interesting and characteristic feature of the Echinodermata is a peculiar apparatus known as a **water vascular system.** It is used principally for locomotion and usually consists of a series of water-filled tubes radiating from a **circular canal** which surrounds the mouth region (Fig. 259). Attached to the radiating tubes are numerous small **tube feet.** When they are projected, little reservoirs, filled with water and called **ampullas,** contract, forcing the water into the tube feet which extend and attach themselves to some object. Then the tube feet shorten by muscular contraction and the animal is slowly pulled in that direction. The tube feet may then release their hold and attach themselves again, and so the process continues. The water vascular system and tube feet may be variously modified in other members of the phylum. Most echinoderms have remarkable powers of regeneration as previously described for the starfish and sea cucumber.

The echinoderms are not particularly important economically. The starfish consumes great quantities of oysters and clams and so comes in for plenty of attention from the oysterman. The eggs of some of the sea urchins are sold for food. The Chinese and other people of the Orient are very fond of the dried sea cucumbers, which are sold as trepang. It is made into soup and other choice dishes.

The living echinoderms have been grouped into the following classes:

Class Asteroidea (*aster*—star; *eidos*—resembling). Starfishes. Arms are not sharply marked off from the disk.

Class Ophiuroidea (*ophis*—serpent; *oura*—tail; *eidos*). Brittle stars. The arms of these forms are sharply marked off from the disk.

Class Echinoidea (*echinos*—hedgehog; *eidos*). Sea urchins and sand dollars. They have no arms but are globular or disk-shaped animals covered with spines.

Class Holothuroidea (*holothurium*—water polyp; *eidos*). Sea cucumbers. Exoskeleton with spines missing. Body wall is muscular and contains small calcareous plates.

Class Crinoidea (*krinon*—lily; *eidos*). Sea lilies. The arms are usually branched, and the animal may be temporarily or permanently attached by a stalk. They were very abundant in geologically ancient times.

CHAPTER XIV

THE ANIMAL KINGDOM (*Continued*). WHAT ARE CHORDATES?

PHYLUM CHORDATA

(*chordos*—a string)

In this last great group we find animals which have at some time in their life a **dorsal, tubular nerve cord** and a supporting endoskeleton. The first indication of the endoskeleton is a long gristlelike rod

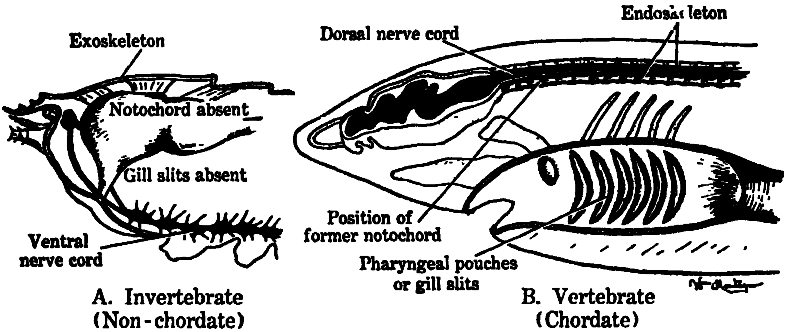


FIG. 260. Diagrams showing fundamental differences between an invertebrate and a vertebrate animal.

called a **notochord** extending the length of the body dorsal to the intestine. **Pharyngeal pouches** are always present. There are a number of these paired pouches which, pushing out from the pharynx, may break to the exterior. We might say in passing that the notochord of human beings and of other higher animals has disappeared in the adult, having been replaced by a backbone. However, one of the pharyngeal pouches still persists as the Eustachian tube (Fig. 260).

We have just reviewed a number of phyla of animals which showed an extremely wide variation in size, shape, and structure. Nevertheless in this varied assemblage we have found a few rather constant characteristics. Thus, invertebrates never have a dorsal tubular

nervous system, a notochord, or pharyngeal pouches. So we see that the invertebrates are quite distinct from this last group, the chordates, the bulk of whose membership consists of the vertebrates. Man, birds, snakes, frogs, and many other animals belong to this phylum. The animals just mentioned, although chordates, are grouped together and known as **vertebrates** (*vertebra*—joint) because they have a jointed vertebral column or backbone.

Primitive Chordates

It so happens that there are some animals which, although they have no backbone, possess chordate characteristics, i.e., notochord, pharyngeal pouches, and a dorsal, tubular nerve cord. In most of these animals the notochord persists throughout life and is the endoskeletal structure.

One of these groups (Subphylum Hemichorda) includes a small, wormlike form called *Dolichoglossus,* which lives in the sand of the sea. It was formerly classified with the worms until biologists discovered its notochord, dorsal nerve cord, and pharyngeal pouches. Further interest attaches to this animal because its larval stage resembles that of the echinoderms, mollusks, and annelids, a fact that has led some zoologists to think that perhaps chordates had their origin from the same common ancestors as these invertebrates. Some biologists today are inclined to return these animals to their former classification with the worms.

The sea squirts are primitive chordates which belong to the Subphylum Urochorda. Early in life they are active swimmers. Some species, however, eventually settle down and degenerate. Their bodies are surrounded and protected by a tunic whose chemical composition resembles that of cellulose, which, as may be recalled, is found almost exclusively in the plant kingdom. Water constantly passes into the mouth and is strained through a much-perforated **pharynx.** Here food and oxygen are removed. The water is then expelled, often quite forcibly, through another opening called the **atriopore.** The sudden ejection of water is responsible for the name "sea squirts." As the food particles pass through the pharynx, some of them become entangled in a sticky mucus produced by the glandular cells of a ciliated groove **(endostyle)** on the floor of the pharynx. The rope of mucus with its entangled food particles eventually passes into the **intestine.**

Probably the best known of these lowly chordates is the lancelet or amphioxus. (These animals belong to the Subphylum Cephalo-

chorda.) *Amphioxus* has received much attention because of a suspicion that it might be one of the ancestors of the vertebrates. It has a **notochord** which persists throughout life. In the **pharynx** are numerous paired **pharyngeal pouches** opening to the outside (Fig. 261). The **endostyle** is found in the floor of the pharynx. The mus-

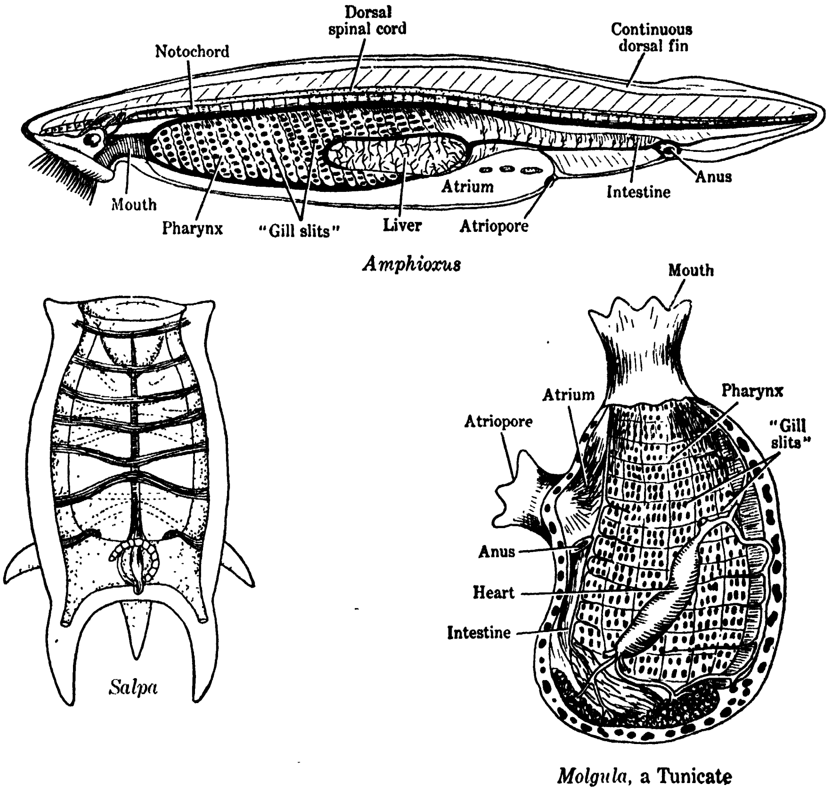


FIG. 261. Some primitive chordates.

cles of the body wall are arranged in two longitudinal lines of bundles or **segments.** There is a continuous dorsal **finfold** which expands into a broad **tail fin** and continues a short distance ventrally, as the **ventral fin,** to the **atriopore.** In front of the ventral fin are two lateral folds. We have included this detailed description because this is the same general arrangement of fins found in the embryonic true fishes. However, as fins develop in fishes, the continuous dorsal finfold disappears in certain regions and from the lateral folds come the pelvic and pectoral fins, the forerunners of the paired fore and hind limbs of the higher vertebrates.

VERTEBRATES

We have already made a somewhat intensive study of vertebrates in our earlier discussions of anatomy and physiology. We shall see that these discussions deal with general fundamental principles that will help us to understand the variations in form and structure found in the different classes. The following review may be helpful. In vertebrates there is always present a jointed **dorsal vertebral column** or backbone of either bone or cartilage which supports the animal and protects the **dorsal nerve cord.** Along the sides of the **vertebras** making up the backbone are attached ribs and usually two pairs of locomotor organs—fins, legs, or wings. In front the skull protects the brain. The ribs support the body wall, which in turn encloses the coelom or body cavity in which are found the digestive system, the heart, and often the breathing mechanism. Breathing is done by gills or lungs, sometimes by both. The nervous system is made up of a well-defined brain and spinal cord. We shall now examine some of the most important groups of vertebrates.

Class Agnatha (*a*—without; *gnathos*—jaw) **(Cyclostomata).** This most primitive vertebrate class includes the fishlike lampreys and hagfishes, animals living in both salt and fresh water. They lack a lower jaw and paired appendages. The notochord persists throughout life, the vertebras are rudimentary, and the cranium does not completely enclose the brain. The skeleton is completely cartilaginous. The animals attach themselves by their suckerlike mouths to the surface of a fish and rasp off the flesh of the victim. They are of no great economic importance.

Fishes. Formerly all fishlike animals were grouped under Class **Pisces** (*piscis*—fish). However, there is a tendency now to change the grouping of these animals and with some justification. We plan to give a general description of fish and then a somewhat more detailed discussion of two of the classes.

Fish are vertebrates which spend their entire lifetime in the water. The usually pointed head is united directly to the smooth, scaly body, which is driven easily and rapidly through the water by the graceful waving of the tail. Unpaired **dorsal** and **ventral fins,** as well as paired **pectoral** and **pelvic fins,** are usually present to assist in guiding the fish in its course and to aid in swimming (Fig. 262). Sometimes these pectoral and pelvic fins serve to support the animal as it rests on the bottom—a foreshadowing of the future limbs of the higher vertebrates. In some fishes there is present an air sac or swim bladder located in the middorsal region of the body cavity. This assists the fish in maintaining a position at various levels in the

water (Fig. 262). The amount of gas present in the swim bladder is regulated to some extent by the fish, but when fishes from moderate depths of the sea are exposed to the relatively low surface pressure their air bladders become so distended that they cannot sink again.

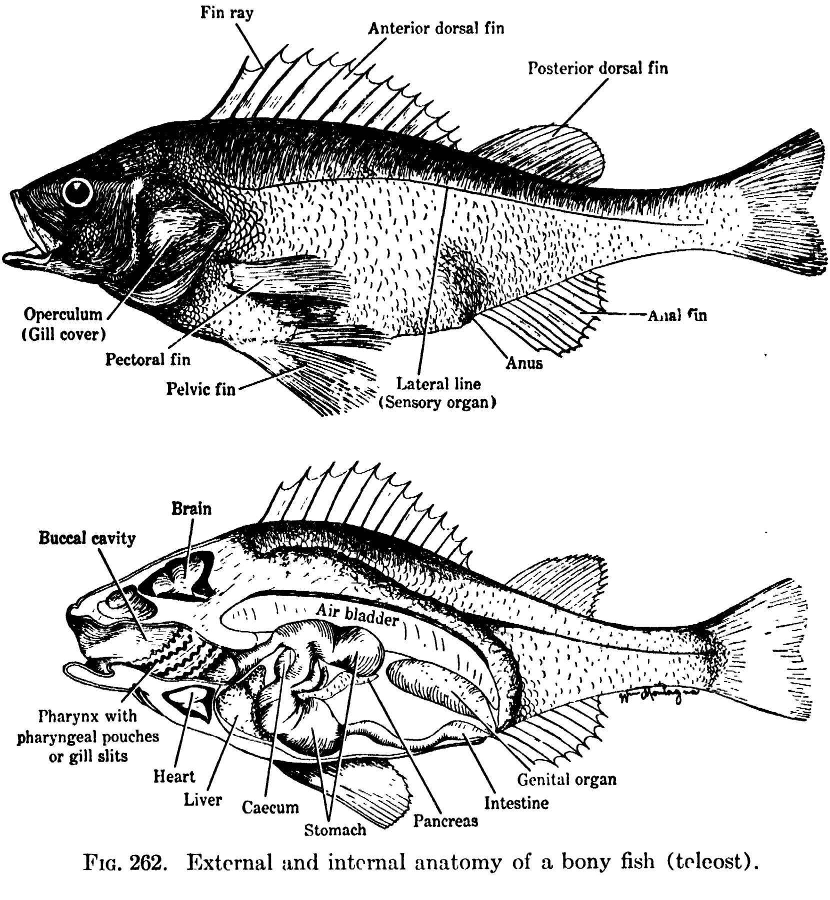


FIG. 262. External and internal anatomy of a bony fish (teleost).

Not all fish move by the customary mode of swimming. Some tropical forms may work their way along the shore by means of their pectoral fins and tail. The climbing perch may be found on roots of trees along the water, and certain flying fish may jump from the water, spread their pectoral fins, and soar along for several hundred yards before submerging again.

The different kinds of fishes consume a great variety of foods. The black-swallowers eat fish larger than themselves, and others, such as the herring, eat annelids and various plants. It has been said

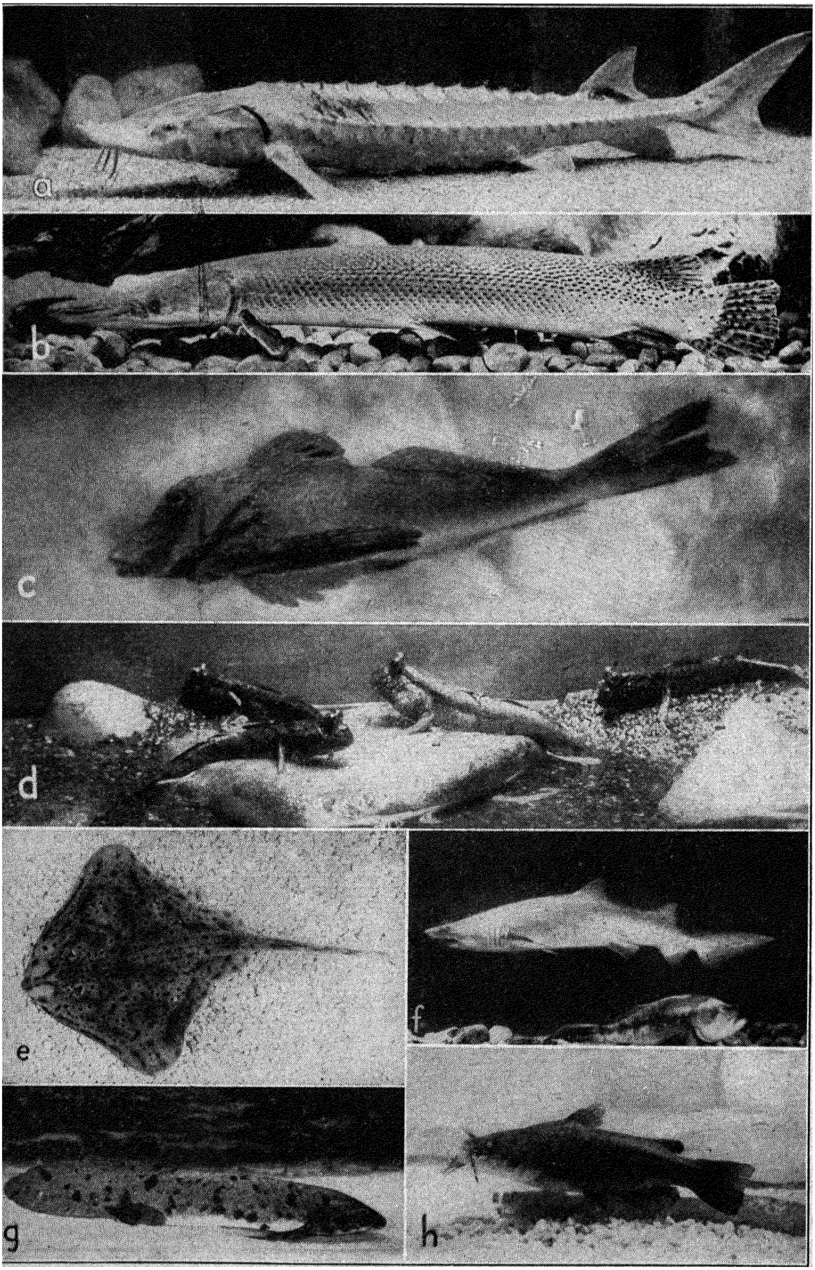


PLATE XIII. Fishes (class Pisces). *a,* lake sturgeon; *b,* alligator gar; *c,* sea robin; *d,* mud springer; *e,* skate; *f,* sand shark; *g,* Australian lung fish; *h,* catfish (bullhead). *Photographs furnished by the John G. Shedd Aquarium, Chicago.*

that the herring catch can be estimated from the number of sunshiny days, so important is plant life in their diet. Many food fish depend entirely upon very small plants and animals that live near the surface of the water of lakes, ponds, and seas, known collectively as **plankton.**

Most of us know that a fish breathes by means of **gills.** Gills are readily seen as J-shaped rows of filaments attached to the **gill arches,** which are the walls separating the pharyngeal pouches. Water containing oxygen is gulped in through the mouth. It passes out through the four or five gill slits and bathes the thin-walled gills, which are well supplied with blood. Oxygen enters the blood and carbon dioxide is given off.

Fish are cold blooded. The heart receives and pumps only venous blood, which enters the single auricle and passes to the lone ventricle that forces it out through paired **afferent arteries** into the gill arches and the gills. The blood, oxygenated in the gills, leaves by the **efferent branchial arteries,** which lead into the aorta (Figs. 79 and 262). A pair of kidneys removes the nitrogenous wastes from the blood.

Chondrichthyes (*chondros*—cartilage; *icthys*—fish). The Chondrichthyes are marine animals and include the sharks and the very much flattened rays. They have a skeleton of cartilage and usually a ventral mouth. Some sharks may reach a length of thirty to forty feet. Sharks are voracious feeders on fish and other animals. Authentic instances are on record of sharks attacking man, but the greatest damage incurred by man from sharks and dogfish is the tearing of his nets and fishing gear. In a single year, the New England fisheries sustained a loss of $400,000 as a result of the damage wrought by these fish. Some of the rays inflict painful and often poisonous wounds by the lashing of their spiny tails. The torpedo or electric ray is able to generate a charge of electricity which may disable a man for as much as a day.

In America and abroad these fishes are used to some extent for food. Some of the flesh is canned and sold under a trade name. They are also used for fertilizer and oil. A basking shark may yield as much as a ton of oil, most of which is extracted from the liver.

Osteichthyes (*osteon*—bone; *ichthys*). The Osteichthyes are known as the bony fishes or true fishes. Most of them have a complete bony skeleton and air bladder. The mouth is terminal. More than 12,000 different species are distributed through waters everywhere and are familiar to us as various types of game and food fish.

Osteichthyes are extremely valuable to man as a source of food, and fishing is an important occupation. It is estimated that more than 10,000,000,000 herring alone are caught annually by British and

American fishermen to be smoked, salted, and packed for distribution. In France 100 sardine canneries have turned out more than 5,000,000 cans annually, and in Maine more than 500,000 cases is the yearly output. When we attempt to estimate the amount of money

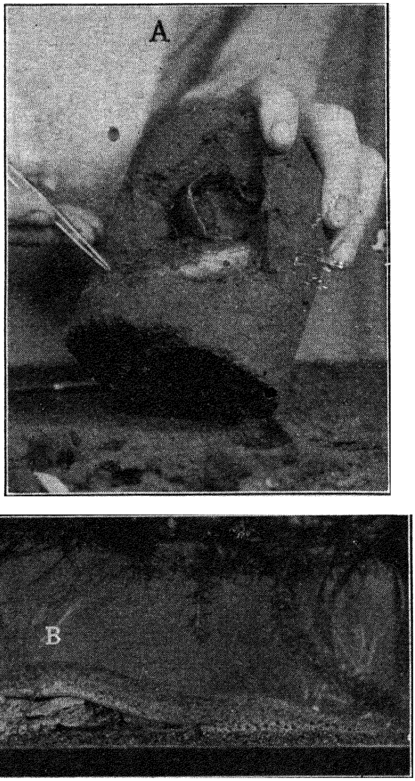


FIG. 263. The African lung fish (*Protopterus*). *A*, lung fish in mucus-lined cocoon in block of mud, estivating. *B*, lung fish in aquarium. *Photographs furnished by the General Biological Supply House.*

invested and the number of people employed in cod fishing, salmon canning, mackerel fishing, and countless other related activities, we realize that here is a biological industry involving billions of dollars and millions of people.

In the light of what has just been said, we can understand at once that measures must be taken to insure a continuing supply of fish. *Nature's store of living creatures is never inexhaustible.* So now we are not only catching fish but also rearing them. Fish culture was practiced by the Chinese and the Romans, but we did not start it in

the United States until about 1865, when the Bureau of Fisheries was established. This bureau is supplemented today by many state and private hatcheries. The government hatcheries not only make studies of the food habits, breeding habits, and habitat relations of fish but also rear young fish.

In the hatcheries the eggs are stripped from the females and fertilized by mixing with spermatozoa from the male. The zygotes are carefully kept in pure aerated water at proper temperature for their development. The young fish are reared under favorable conditions and protected from their natural enemies. In this way millions of eggs and young fish are saved which otherwise might be destroyed. When the fish reach a certain size they are shipped in large cans to certain points for the restocking of streams, ponds, or lakes. In shipping, special care is taken to keep the water cool and well aerated.

Included among Osteichthyes is the lung fish, found in Australia, Africa, and South America. They breathe not only by means of gills, which may be either external or internal, but also by lungs which are developed from the air bladder, hence the name "double-breather." When the ponds and streams dry up, certain of these fish burrow into the mud and form a mucus-lined cocoon. Here they live during the hot, dry season; in other words, they **estivate** (*aestas*—summer) until conditions favorable for active life return. Some of these fish are shipped to this country in a block of mud and, on arrival, are placed in water and "thawed out" (Fig. 263).

Class Amphibia (*amphi*—double; *bios*—life). In this class of vertebrates we find among other animals the frogs, toads, water dogs, and newts. Amphibians are both aquatic and terrestrial. They spend all or part of their life in the water, either as adults or as free-swimming fishlike tadpoles. The tadpoles breathe by means of gills which may be later supplemented or even supplanted by lungs. Not only is there an oxygen-carbon dioxide exchange through the gills and lungs but the skin also plays an important role, hence the skin must always be kept moist. Modern Amphibia have no scales, feathers, or hair, and their limbs bear digits which have neither nails nor claws. They have a heart made up of two auricles and a ventricle, and they are cold blooded. In cold weather many of these animals **hibernate** (*hibernus*—wintry) in the mud of ponds and streams. Amphibia hold a peculiar interest for us because their anatomy and physiology throw some light on the gradual shift from purely aquatic to land animals.

ORDER CAUDATA (*cauda*—tail) OR URODELA. These Amphibia keep their tails throughout life. In the order Caudata we find water dogs or hellbenders, mud puppies, and other salamanders and newts. Sala-

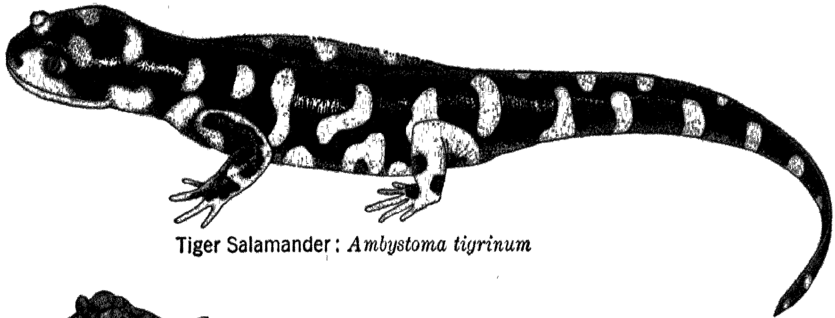
manders and newts are often found under logs and stones, in moist and swampy places, and around springs. The uninitiated call them "lizards," but they can readily be distinguished from lizards by the absence of claws on the toes or scales on the skin and by their choice of moist living quarters. These little animals live on insects and insect larvas for the most part. Many of them are very pretty. Some are vermilion spotted; others are jet black with ivory blotches; and still others are beautifully striped. They are harmless.

The water dog or hellbender (*Cryptobranchus*) and the mud puppy (*Necturus*)—not a young water dog—are found mostly in the Mississippi River and its tributaries, and these hellbenders may reach a length of twenty or thirty inches. The hellbender of Japan, sometimes five feet in length, is used for food by the Japanese. The mud puppy is about twelve inches long. All these animals are harmless to man and are the scavengers of streams. The water dog may eat some fish but it is of practically no economic importance from that angle, yet the fisherman loathes these animals, claiming they are poisonous and great killers of fish. In some localities enthusiastic but misguided sportsmen hunt and slaughter them wholesale as "vermin."

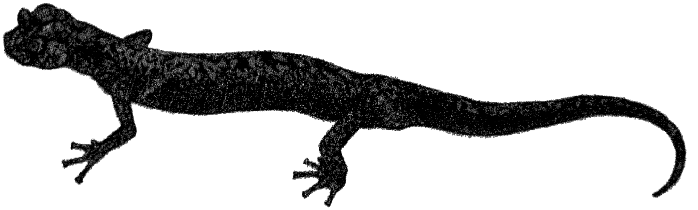
ORDER SALIENTIA (*salio*—leap) OR ANURA. These are tailless Amphibia—our friends, the frogs and toads (Fig. 264). They start in life usually as swimming, gill-breathing tadpoles but later metamorphose into leaping, lung-breathing adults. Frogs and toads are almost completely insectivorous. They have a very flexible tongue attached in front. This they flip out, capture the moving insect, and pull the prey back into the mouth where it is swallowed without being chewed.

Frogs and toads usually lay their eggs in jellylike masses in pools and streams. Here the eggs hatch into small tadpoles which begin life as vegetarians but become carnivorous when adult. Toad tadpoles develop into tiny toads which often appear during a shower on their aquatic Emancipation Day, when they are seen in such numbers that many people think they were "rained down." Besides the ordinary frogs and toads there are tree frogs which, having toes equipped with sucking disks, climb without any difficulty. Some of the tropical tree frogs never leave the tree tops but lay their eggs in pools of water collected in the trees or leaves. One tree frog in Java rolls up a leaf to make a nest.

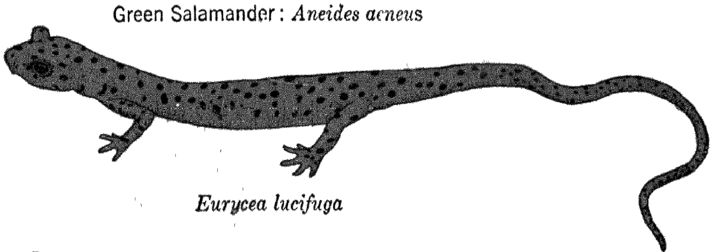
The Salientia are useful to man as insect destroyers. Kirkland found that 88 per cent of a toad's diet was insects and about 16 per cent was cutworms. He found further that a toad would eat four



Tiger Salamander: *Ambystoma tigrinum*



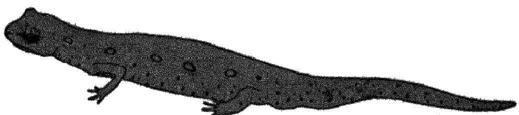
Green Salamander: *Aneides aeneus*



Eurycea lucifuga

Jordan's Salamander: *Plethodon jordani*

Marbled Salamander: *Ambystoma opacum*



Newt (Land stage) *Triturus viridescens*

Wm Montagna

PLATE XIV. Types of Caudata.

stomachfuls every 24 hours. At this rate one toad would account for almost 10,000 insects in three months! On this basis every toad is worth about $20 a year to the farmer and gardener. Frogs are useful not only as insect destroyers but also for food. The flesh is best in the autumn and winter. They are used extensively in experimental biological work.

Some attempts have been made to operate frog farms. One farm in Ontario, which has been in existence for more than 25 years, in one year had an output of 5,000 pounds of dressed frog legs and 7,000 living frogs. However, there are

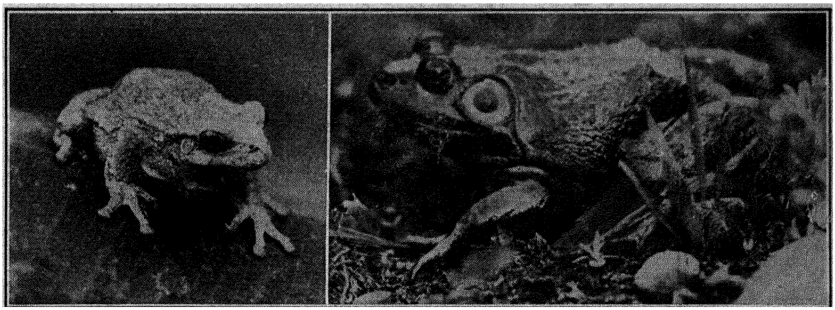


FIG. 264. Types of Class Salientia. *Left,* tree frog; *right,* bull frog (*Rana*). *Photograph on left furnished by General Biological Supply House; photograph on right by R. L. Fricke, Carnegie Museum.*

difficulties for the frog farmers. Birds, turtles, snakes, and other animals eat tadpoles and even adult frogs. Moreover, since frogs will eat only moving insects, a natural pond with rank vegetation is one of the prime requisites for the venture.

ORDER APODA (*a*—without; *podos*—foot). Apoda are degenerate, limbless, snakelike Amphibia found only in tropical countries; imbedded in the skin are scaly skeletal plates. The animals are unimportant economically.

Class Reptilia (*repere*—to crawl). When the word reptile is mentioned most of us think of snakes, for snake, unfortunately, is too often our only concept of a reptile. However, Reptilia include not only snakes but also turtles, lizards, crocodiles, alligators, and others. These animals are found either on land or in the water. We can readily identify reptiles because the body is covered with **scales** and, with the exception of snakes, the digits of the limbs have **claws.** They are **cold blooded,** and most of them have a heart made up of two auricles and two ventricles. In most reptiles the septum between the ventricles is not completely closed. Another peculiarity is the attachment of the skull to the backbone by one **condyle** on the base of the skull (Fig. 265).

Reptiles have become independent of the water as a necessary dwelling place for any part of their life. It is not necessary for them to return to the water to lay their eggs, since the developing embryo is inclosed in a water-filled sac called the **amnion.** Also an **allantois** is present to care for excess waste. As someone has put it, each individual embryo now has its own private pond. There is a greater lung growth, owing to the development of folds forming additional chambers which increase the surface. Gills are absent from the list

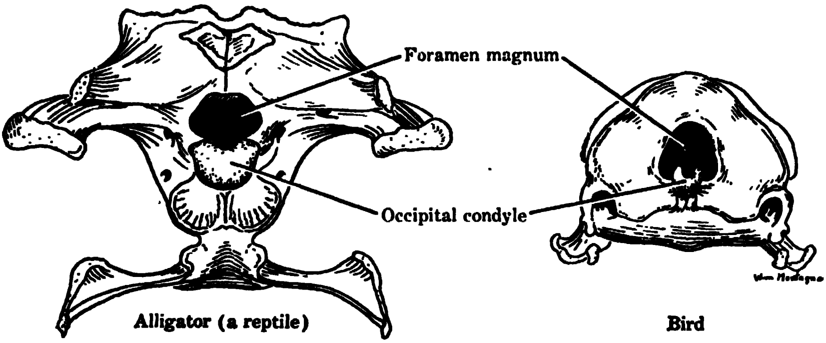


FIG. 265. Comparison of the skull of a bird (chicken) with that of a reptile (alligator). Note the opening (foramen magnum) through which the spinal cord passes. Below this opening is the basioccipital bone on which is found a single protuberance known as an occipital condyle which articulates with the backbone.

of reptile structures. The moist, soft skin of the Amphibia is no longer necessary as an accessory respiratory organ. Instead, the dry and scaly skin of reptiles prevents the loss of water. The various adaptations just described make it possible for reptiles to live in dry sandy regions far removed from water. We shall now examine some of the most important orders of living Reptilia.

ORDER SQUAMATA (*squama*—scale). The Squamata are lizards and snakes. Strange as it may seem, a snake in many respects is a lizard minus appendages. The lizards have a rather small head attached to the trunk by a neck. Usually a long tail is present. The body is often covered with colored scales arranged in different color patterns. The chameleon, a lizard, can change its color to harmonize with its surroundings—a mode of protection. Another very interesting protective feature possessed by some lizards is the power to break off certain regions of the tail automatically. This power is called **autotomy.** It probably explains the fable of the "glass snake," which, when broken into pieces, was supposed to reassemble the

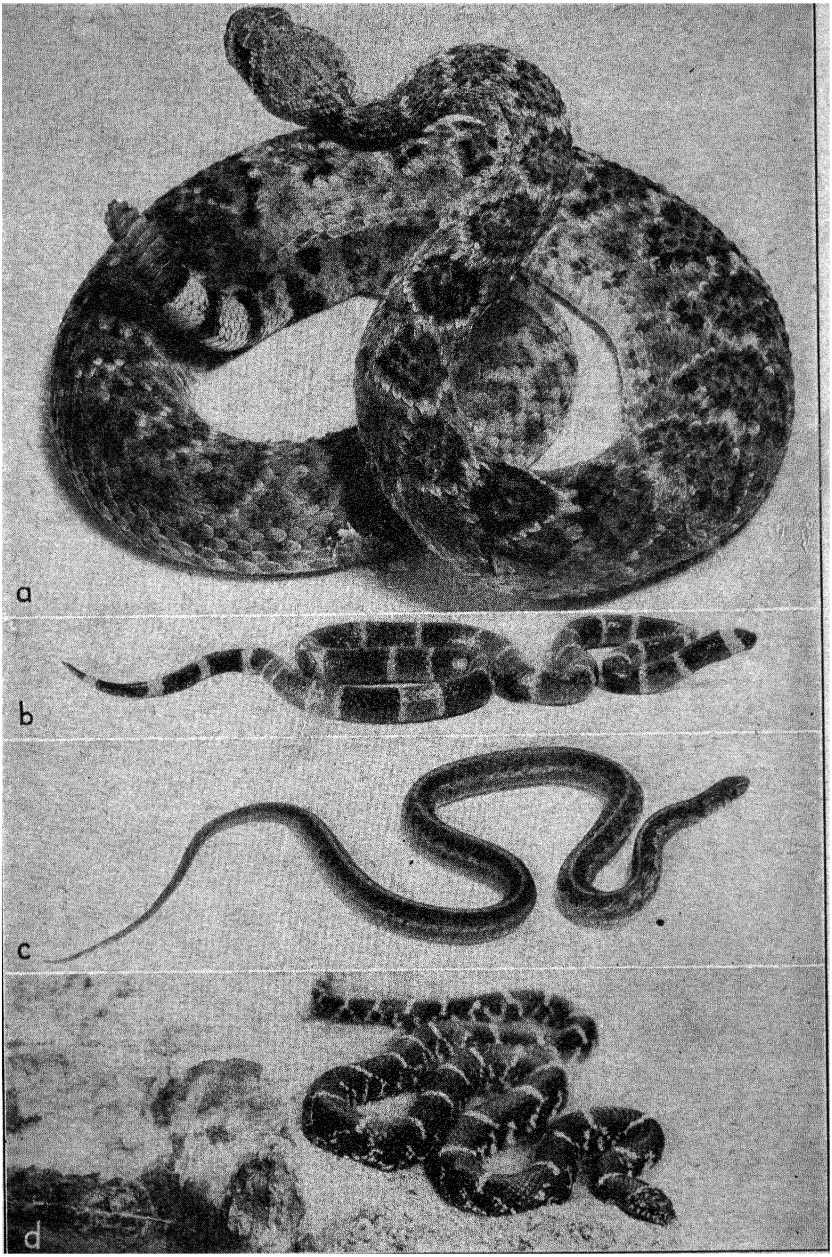


Plate XV. Class Reptilia (snakes). *a,* rattlesnake; *b,* coral snake; *c,* garter snake; *d,* chain snake. *Photographs a, b, and c furnished by the Fish and Wildlife Service, U. S. Department of the Interior. Photograph d furnished by the National Zoological Park.*

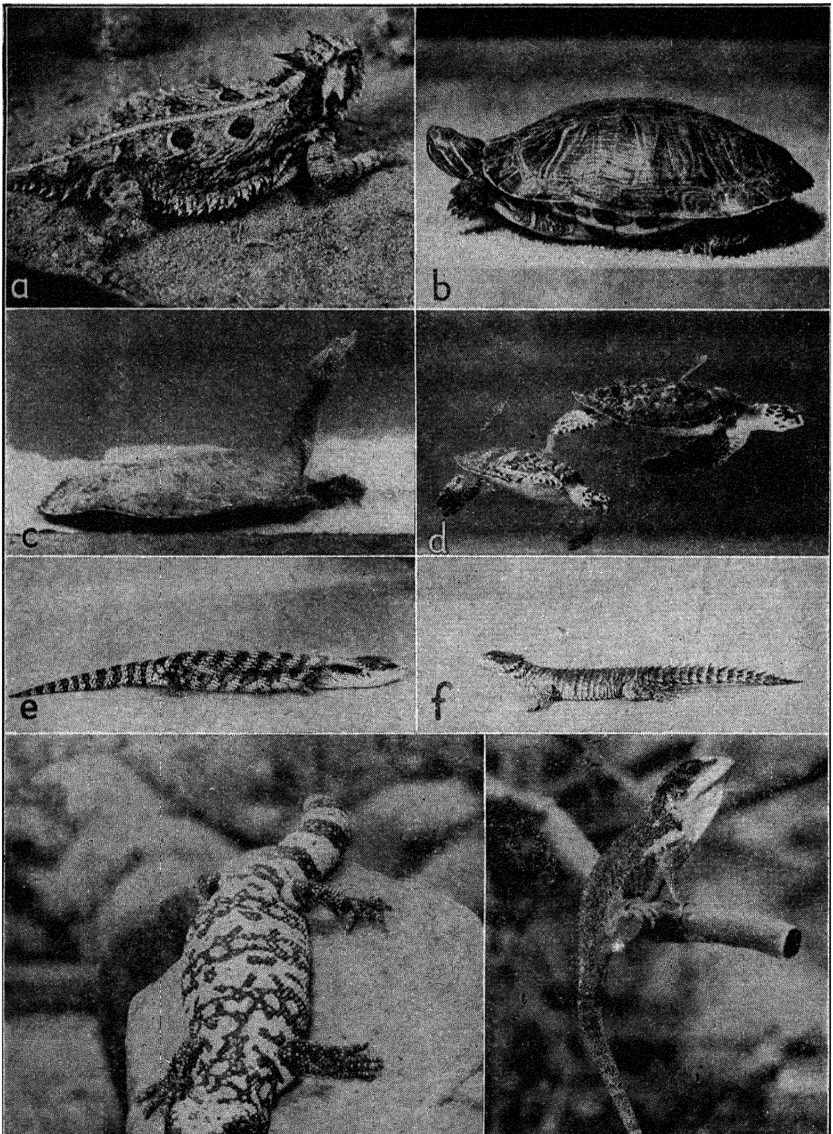


Plate XVI. Reptilia (turtles—Order Testudinata; lizards—Order Squamata). *a,* horned toad; *b,* cumberland terrapin; *c,* soft-shelled turtle; *d,* hawk's-bill turtle; *e,* blue-tongued lizard; *f,* spiny-tailed lizard; *g,* gila monster; *h,* giant amolis. *Photographs a, b, furnished by the General Biological Supply House; c, d, John G. Shedd Aquarium; e, f, g, h, National Zoological Park.*

pieces in proper order when all danger was past. The "glass snakes" are really limbless lizards.

Some of our tropical lizards are equipped with vacuum-cupped toes which enable them to chase insects along the walls and ceilings of rooms. The chameleon has a club-shaped tongue with a sticky tip, and it shoots out this tongue to an incredible distance to capture insects. The flying dragon is a rather small lizard which glides from tree to tree by means of its lateral "wings," made up of the rib-supported sides of the body. Another lizard we hear much about is the "horned toad," which burrows in the ground and is able to withstand extreme weather conditions. However, the report that it can remain alive when sealed in stone for a period of years is incredible. When cornered and in danger, the horned toads have the curious habit of shooting blood out of the eye to a distance of two feet or more.

The only poisonous lizards are the Gila monsters or beaded lizards found in southwestern United States, Mexico, and Central America. These lizards are covered with beadlike scales arranged in bright red and other colored bands around the body. The poison glands are in the lower jaw, and the animals are able to deliver a bite which Ditmars, an authority on reptiles, considered "dangerously poisonous to man."

Everyone readily recognizes a snake by its long, scaly, cylindrical, limbless body. Pythons and boas, however, have bones of vestigial limbs imbedded in the muscles under the skin. This, together with other evidence, seems to indicate that the ancestors of the snakes were four-footed, lizardlike animals. The willowy slenderness of the snake brings about curious adaptations. One lung has practically disappeared, the urinary bladder is missing, and the various other internal organs are peculiarly arranged.

One naturally wonders how these limbless animals crawl and swim, and the mechanism is quite interesting. The two or three hundred vertebras are joined in a flexible column by ball-and-socket joints. Attached to most vertebras is a pair of ribs fastened at the free end by muscles to the broad ventral scales. These muscles contract, causing the ventral plates to strike backward on the ground and help, with the wriggling of the body, to drive the animal forward.

✓ Snakes never chew their food and quite often swallow animals much larger in diameter than themselves. The snake's lower jaws are attached very loosely to the skull and are held together in front by an elastic ligament. Thus the entire palate and lower jaw are very flexibly articulated so that a garter snake, for instance, can easily swallow a large toad. The teeth, almost as fine and sharp as

needles, curve backward, an arrangement that helps to keep the bulky food moving into the mouth and on down the throat. In the poisonous snakes some of the teeth are either grooved or hollow. They are the fangs through which the poison passes from the poison glands down into the wound. The little red, forked structure which darts out from the snake's mouth is the tongue and not the fangs.

Snakes are either oviparous or viviparous. Oviparous snakes lay their eggs under stones, logs, or leaves or bury them in the soil. The eggs depend upon the heat of the sun for incubation. The viviparous garter snakes retain the eggs within the body until they hatch.

Contrary to popular belief, most snakes are harmless. In fact, many snakes are man's friends. The little green grass snakes crawl up on weeds, hunting insects which they eat. Other insectivorous snakes are the brown or ground snakes, most of which live in the soil. They are dull brown above; ventrally they may be white, yellow, or pink. The rat snakes are very useful as rodent destroyers; among them are the fox snake, the spotted chicken snake, and the pilot blacksnake. The common blacksnake or blue racer is not only harmless but indeed very useful in destroying field mice, rats, and other rodents. In spite of reports to the contrary they do not wrap around a person and squeeze him to death. The garter snakes, although non-poisonous, are of negative value because they are great destroyers of frogs, toads, and young birds and bird eggs. The hog-nosed snakes are harmless snakes called blowing vipers and puff adders. They have a flat, somewhat triangular head resembling that of the poisonous snakes. The head and the habit they have of blowing and hissing when disturbed have led to the erroneous belief that they are very poisonous. The blowing and hissing are merely bluff.

No one actually knows how many people die every year from the bite of poisonous snakes, but estimates vary from 12 persons in Australia to 20,000 people in India. Pope thinks this last figure grossly exaggerated, but it is estimated that in the United States alone the number is approximately 160. Of the people bitten in the United States who receive proper treatment only 3 or 4 per cent die, whereas 15 per cent of those untreated die.

The poisonous snakes responsible for most of the deaths in the United States are rattlesnakes and water moccasins, which belong to the pit-viper group. Another pit viper in the United States which is blamed for many deaths is the copperhead, but data show that less than 1 per cent of the people bitten by copperheads die. The other poisonous snakes in the United States are the coral snakes, but it is rarely that they inflict a bite that is fatal.

Three methods are found among snakes for the injection of poison into the wound. In some snakes the fangs are grooved and are the hindmost teeth of the upper jaw. Snakes thus equipped must hang on and chew in order to get the poison into the wound. The second type of fang, found in the cobras and their allies, is rather short and rigidly set. Although the tooth has a canal, there still remain strong traces of an external groove. The most efficient type of fang is found in the viperine group such as the water moccasin and rattle-

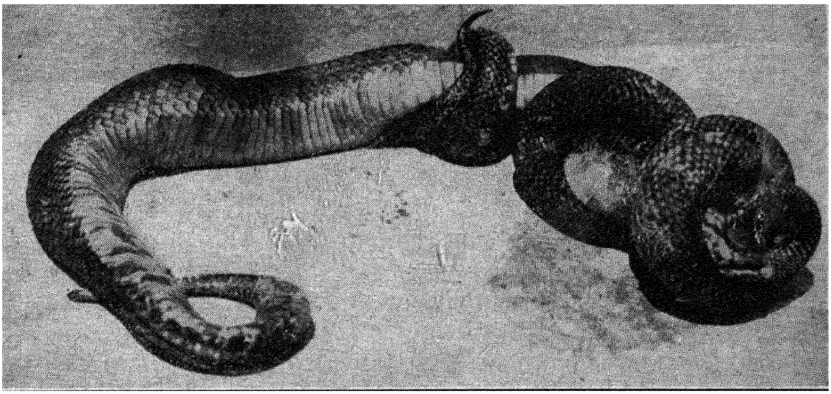


FIG. 266. King snake killing a cottonmouth snake. *Photograph furnished by Ross Allen Reptile Institute, Silver Springs, Florida.*

snake. These fangs are rather long and slender and are found near the front of the mouth rigidly attached to a movable bone. Located near the eye is the poison gland drained by a duct opening into the hollow fang. This apparatus works like a hypodermic syringe.

Fresh snake venom is usually a yellow, occasionally colorless, liquid. It is tasteless and odorless. If exposed to ultraviolet light or treated with nitrate of silver or potassium permanganate it loses its poisonous qualities. In preparing antivenin, the dried venom is dissolved and a dilute solution is injected into horses in successive doses of ever-increasing quantity. (See Plate I, page 138.) After a few weeks there develops in the horse's blood a substance that neutralizes the poisonous effects of the venom. Antivenin reaches its highest concentration three or four months after the horse has been inoculated. Some of the serum is drawn off from the horse, and the antivenin in it is concentrated by a special process, measured for its antivenin reaction, and then put up for use in measured amounts in small syringes.

Snake venoms contain two types of harmful substances: one type destroys or paralyzes nerve cells, damages the blood vessels, and ruptures the walls of the capillaries; the other is made up of a group of substances and acts by "digesting" the living flesh. In the second type there is an antifibrin ferment which keeps the blood from clotting and consequently causes internal bleeding. The poisons of the pit vipers of the United States contain small amounts of the neurotoxin, whereas the venom of the cobras and their allies is made up chiefly of the nerve-affecting elements. Snake venom lowers the resistance of the blood to infections.

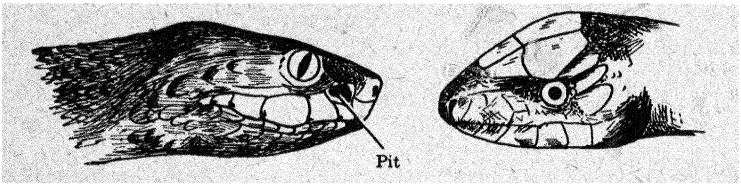


FIG. 267. Comparison of the heads of a poisonous (pit viper) and a non-poisonous snake. On the poisonous snake note vertical pupil and pit. This pit is lacking in the non-poisonous snake, and the pupil is circular in outline.

Treatment for snake bites. First-aid treatment recommended for snake bite includes the following steps: 1. Do not get frightened and lose your courage. 2. Apply a tourniquet above the bite just tight enough to permit circulation of the blood but not the lymph. 3. With a sharp sterile knife make short cuts across the fang wounds one-fourth of an inch deep and one-fourth of an inch long. 4. Suck the wound with mouth, if there are no cuts or sores present, or with mechanical suction apparatus, for twenty or thirty minutes. 5. Administer antivenin. 6. As swelling develops in a limb, make shallow cuts one-eighth inch deep and about as long in a circle around the badly swollen limb. Suck out as much fluid as possible. 7. Do not give alcoholic drinks. 8. Do not cauterize with hot iron or apply the viscera of a freshly killed chicken.

Five families of snakes have members that are poisonous. These members and their distribution are set fourth in the following table.

FAMILY	SNAKE	DISTRIBUTION
Colubridae Fangs at back of the jaw	River snakes	Rivers and bays of East Indies, Malaysia to Northern Australia
	Tree snakes	Central and South America, Texas, and Central Africa

Family	Snake	Distribution
Hydrophidae Short fangs at anterior end of jaw	Marine serpents	Indian Ocean and the western tropical Pacific
Elapidae Rather short, firm fangs at anterior end of the jaw	Cobras	India, Africa, southern China, and Malay Archipelago
	Kraits	India and Malay Archipelago
	Coral snakes (New World)	Southern United States
	Australian black snake, "Purple death" adder	Australia
	Tiger snake	Australia
	Death adder	Australia
Viperidae True vipers without head pits	European viper Tic Polonga Rhinoceros viper Puff adder	Southern Asia, most of Europe and Africa
Crotalidae "Pit vipers," long slender fangs at front of the jaw	Rattlesnakes Water moccasins Copperheads	Abundant in the Americas, southeastern Asia, and East Indies
	Fer-de-Lance	From southern Mexico into tropical South America; Lesser Antilles
	Bushmaster Tree viper	Central and tropical South America

ORDER CROCODILIA (*krokodeilos*—crocodile). This group of carnivorous reptiles, having a worldwide distribution, includes crocodiles, alligators, gavials, and caimans (Fig. 268). They are water-dwelling reptiles having long jaws and webbed feet. Alligators and crocodiles are found in the bayous and streams draining the southern part of the United States. Alligators may attain a length of twelve to fourteen feet. They lay their eggs in nests of decomposing vegetation, the heat of which incubates the eggs. The skins of the animals are used for leather. The annual production of alligator hides amounts to more than 88,000 pounds valued at nearly $7,500.

ORDER CHELONIA (*chelone*—turtle). Chelonia are turtles, terrapins, and tortoises. They are interesting reptiles having toothless jaws and a protective "shell" which is really a transformation of the vertebras, ribs, and sternum into bony plates. The bony plates, in turn, are shingled over by horny plates corresponding to the scales of other reptiles. Here is a group of animals whose hips and shoulder blades lie inside the ribs or, more properly speaking, inside the endoskeleton. How such a reversal came about is still a biological mystery. These reptiles are mostly carnivorous and aquatic. The eggs

are laid in a shallow pocket made in the sand, and there, covered only by a thin layer of sand, they hatch. The young are left to shift for themselves.

Turtles are of interest to man not only because of their peculiar form and food habits but also because of their food value. Many

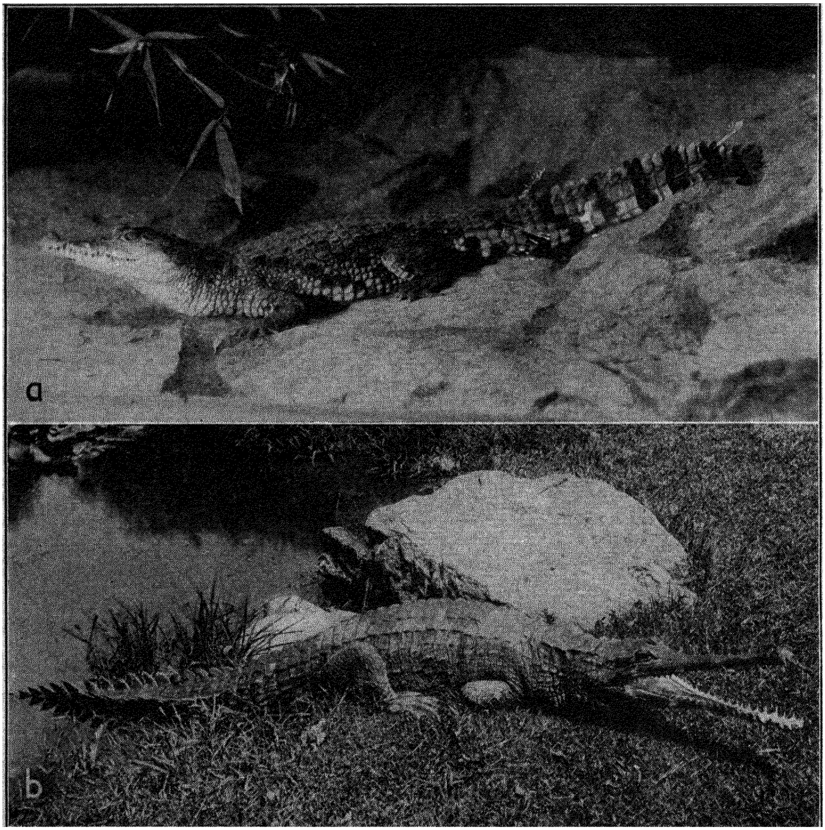


FIG. 268. Class Reptilia (Crocodilia). *a*, alligator; *b*, gavial. *Photograph a furnished by the National Zoological Park; photograph b, by the New York Zoological Society.*

of the fresh-water turtles are quite destructive of fish, frogs, and waterfowl, both young and old. The snappers—the southern alligator snapper may weigh as much as 140 pounds—are ferocious and will snap at almost anything. They are able to pull under the water and drown full-grown ducks. Speaking of size, we must not overlook the giant sea turtles which may weigh 500 pounds, and the giant land tortoises of the Galapagos Islands which may weigh more than

300 pounds. The giant tortoises are vegetarians. Sea turtles are taken when they come on land to lay their eggs, and are also captured at sea by harpooning. These as well as many other turtles are used for food. The diamond-back terrapin is considered quite a delicacy and is reared commercially on terrapin farms. Snapping turtles and soft-shelled turtles make excellent soup. In a single year turtle products in the United States alone were valued at more than $129,000.

The little land turtle or tortoise, properly speaking, is probably the most familiar of all the Chelonia. This turtle with its occasionally initialed and numeraled shell is found wandering about and feeding on berries, earthworms, and insects. The ventral shell or plastron is so hinged that the entire head and the pectoral appendages can be withdrawn into the shell and enclosed by the hinged central shell or **plastron** (*plastron*—breastplate).

ORDER RHYNCHOCEPHALIA (*rhynchos*—snout; *cephale*—head) Here belongs a lizardlike reptile about two feet long found in New Zealand. It is a burrowing, nocturnal animal and interesting because it is apparently a primitive animal which has persisted up to the present. It has a single well-developed pineal eye in the roof of the skull and numerous other peculiarities of the skeleton that are found only in the fossil Reptilia.

Reptiles of the past. The different members of Reptilia that we have discussed so briefly are but a small sample of that mighty group which reached its zenith in variability and size millions of years ago. The record of the vast assemblage is preserved in the fossilized specimens found in the rocks. The state of Kansas at one time was covered by seas in which swam huge plesiosaurs and mosasaurs whose limbs were modified to form paddles somewhat like those of modern whales. Fishlike ichthyosaurs also inhabited these seas, while overhead flew great reptiles called pterodactyls, some of which had a wing spread of twenty feet.

In Wyoming, Utah, and adjacent states there were vast swamps with remarkably dense vegetation. In the swamps there lived huge dinosaurs ("terrible reptiles"), some of which were almost a hundred feet long from the tip of the relatively small head to the end of the long tail. These animals were mostly vegetarians. It is estimated that for a day's ration one of these creatures, which must have weighed many tons, required almost a thousand pounds of vegetation. Judged by the size of the cavities for the brain and the nerve cord, these gigantic reptiles must have been very stupid and sluggish. Their extinction was probably brought about by changing climatic conditions and by the great carnivorous dinosaurs whose jaws were

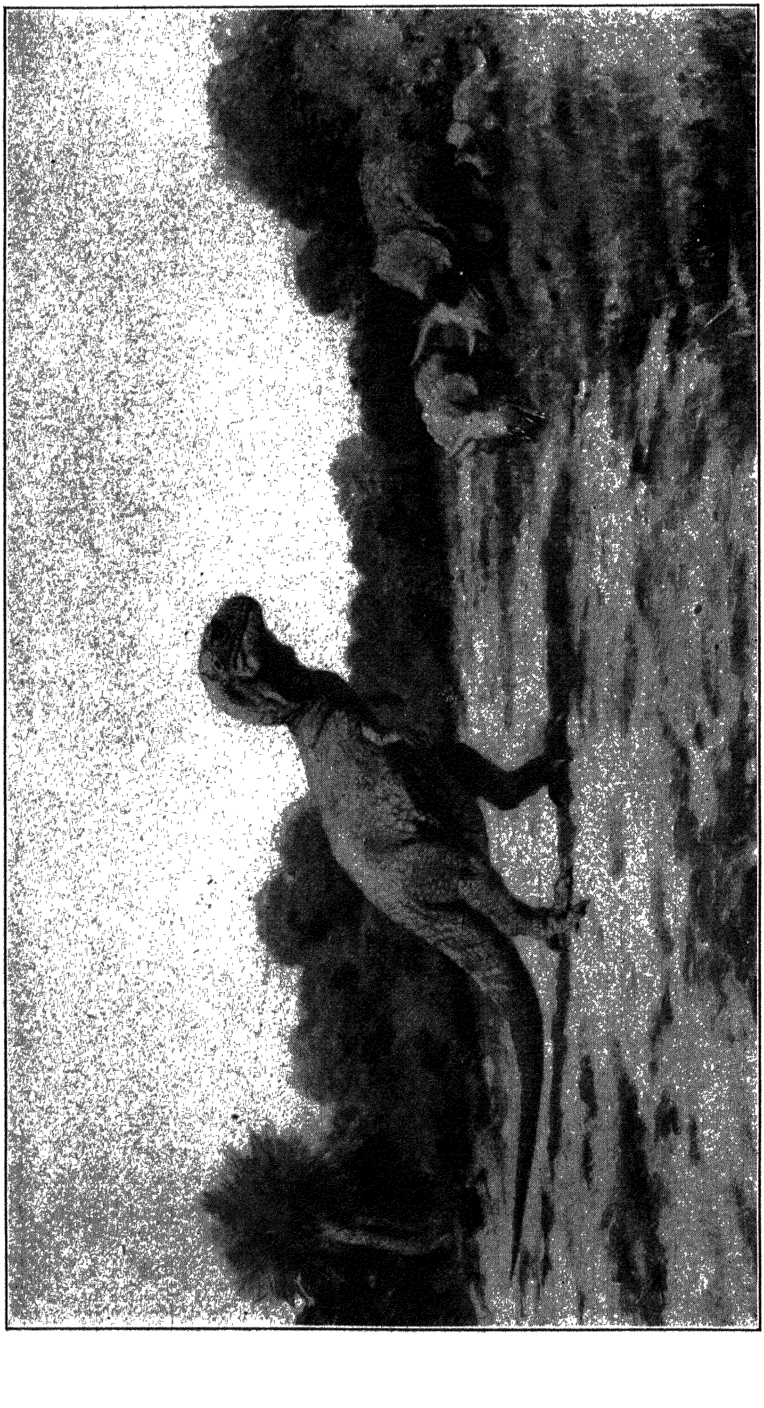


FIG. 269. Restorations of two extinct reptiles, *Tyrannosaurus* (*right*) and *Triceratops* (*left*). *Photographs furnished by the American Museum of Natural History.*

equipped with seven-inch teeth and on whose toes were huge tearing claws. Other factors which may have entered into the downfall of these Reptilia were diseases and the appearance of more intelligent, warm-blooded, rodentlike mammals which may have destroyed their nests and young.

Class Aves (*avis*—bird). Birds differ from all other animals in having **feathers.** The forelimbs are usually adapted for flying. The heart has two completely separated auricles and two completely

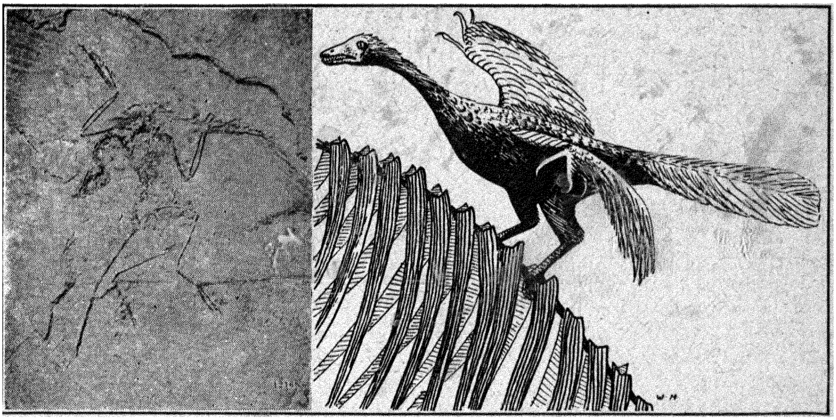


FIG. 270. *Archeopteryx. Left,* fossil clawed imprint; *right,* restoration of *Archeopteryx.* Note the long reptilian tail, and the clawed appendages of the wings. *Photograph furnished by the Victor Animatograph Corp.*

separated ventricles. Thus there can be no mixture of venous and arterial blood. They are warm-blooded animals. Modern birds are toothless.

There is strong reason for thinking that birds are descendants of the Reptilia. Some of the strongest evidence for the theory is furnished by *Archaeopteryx,* an ancient bird about the size of a crow, whose fossil remains were found in Bavaria (Fig. 270). The jaws bore reptile-like teeth, and each wing had three free, clawed digits. The tail was long and flexible, for the vertebras were not telescoped into a little bony mound as in modern birds. On either side of the long tail were rows of feathers. This "missing link," together with the reptilian features found in modern birds, such as one occipital condyle on the base of the skull, reptilian scales on the legs, and feathers closely resembling reptilian scales, certainly indicate that birds are first cousins of the reptiles (Fig. 265).

In modern birds the feathers are grouped in definite regions or tracts and are of three kinds: **contour feathers, down feathers**

(plumulae), and **hair feathers (filoplumes)** (Fig. 271). The contour feather is supported by a stiff axial rod, which in the feather proper is called the **rachis.** On each side of the rachis is a row of parallel filaments called **barbs,** branching from which are **barbules** held together by **hooklets.** The broad part of the feather is known as the **vane.** Down feathers have a soft shaft and no vane. Filoplumes have a slender, hairlike shaft. Feathers form a light, efficient insulator which enables the bird, as a warm-blooded animal, to conserve heat. Birds shed their feathers or molt at fairly regular in-

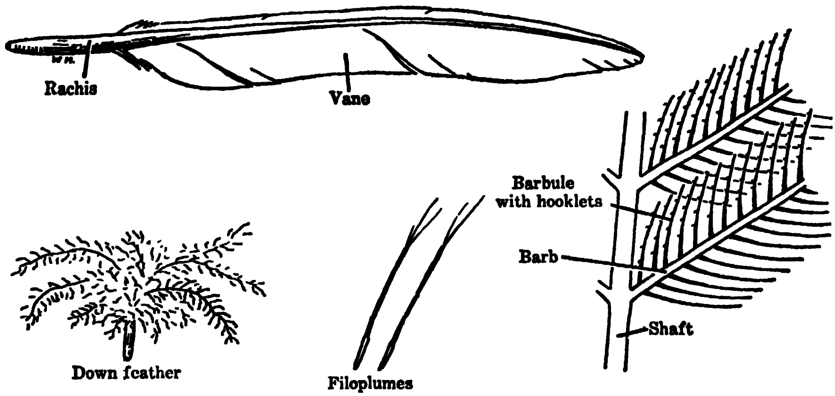


FIG. 271. Types of feathers.

tervals, just as snakes shed their skins. Quite often the color pattern of a bird changes with the coming of the new feathers.

Flying has involved more changes in birds than the mere working over of the forelimbs into wings. The bones in flying birds are made as light as possible by means of air spaces. Some of the bones are even hollow. Often the sternum has a well-developed keel or edge down the center, to which are attached the pectoral muscles that move the wings in flying. For its size the hummingbird has a remarkably large keel, whereas ostriches, cassowaries, and other running birds have no keel on the sternum (Fig. 273). It has been estimated that the wings of a hummingbird make between 600 and 1,000 strokes per minute.

Since the bird depends almost entirely upon flight for protection it may have many partial and interrupted meals. However, in many birds the esophagus may be dilated for food storage, and in the fowls and pigeons a further differentiation of the esophagus is the saccular **crop,** a storage organ. The toothless beak as well as rapid gorging allow for little tearing and grinding of the food. However,

this function is performed by the stomach, which is modified to form the **gizzard,** a highly muscular grinding organ with a tough lining. Usually there are fine pebbles in the gizzard that assist in the grinding (Fig. 59).

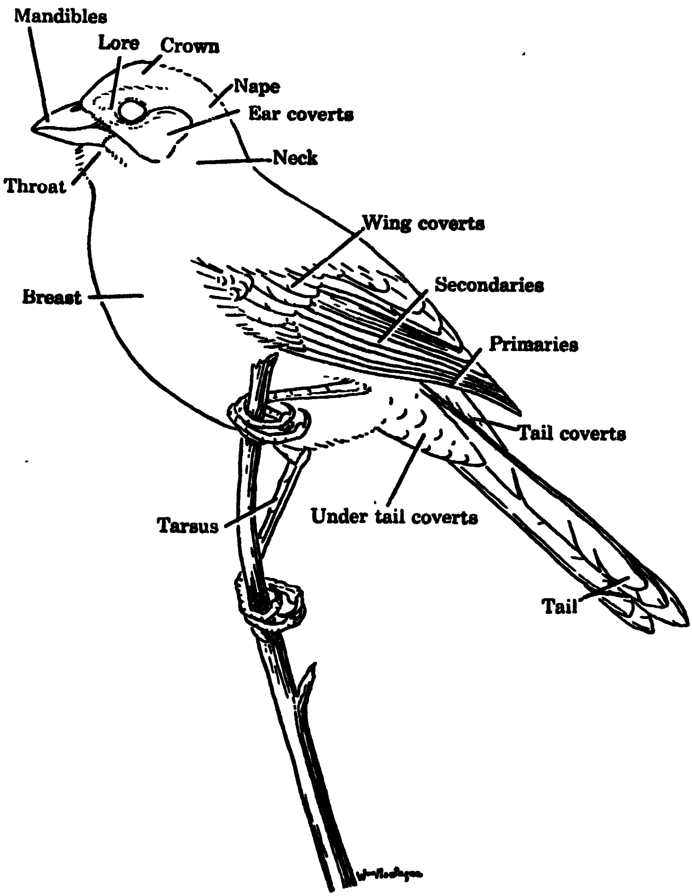


FIG. 272. External features of a bird.

Birds lay eggs which closely resemble those of reptiles. Birds' eggs have a hard shell of calcium carbonate. The egg containing a supply of yolk is fertilized soon after it leaves the ovary. As it passes down the oviduct there is added first the albumen or white, and finally, just before the egg is laid, there is added the shell derived from secretions of the shell glands. The young embryo, as mentioned previously, floats in the amniotic fluid in the amnion and gives off wastes

into the allantois (Fig. 167). Young birds when hatched are in a relatively advanced stage of development, and, with helpful parental care, many of them reach the adult stage.

The Australian bush-turkey, behaving somewhat like the alligator, lays her eggs in a heap of decaying leaves and rubbish which furnishes the heat for incubation. The nighthawk and whippoorwill lay their eggs on the bare ground. Most birds build nests woven of grasses, small twigs, and other materials. They often line their nests. The American robin lines its nest with soft grasses and roots. One of the swifts of northern Borneo makes a nest which is more or less a

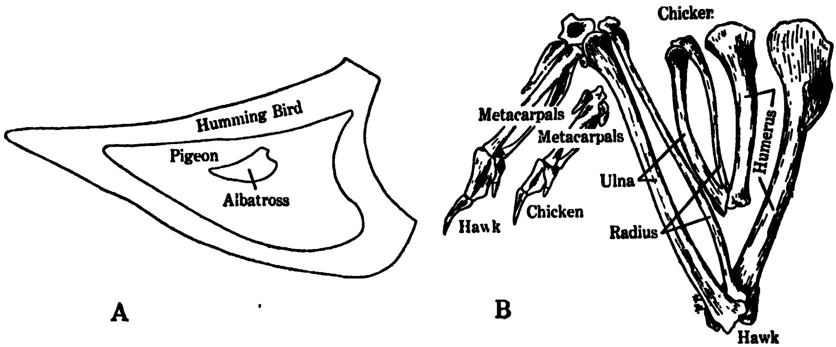


FIG. 273. Relation between flight (function) and structure in birds. *A*, comparison of the sternums of different birds, assuming that all have the same weight. The albatross is a soaring bird; the wings of the hummingbird beat so rapidly that they become almost invisible. It should be noted that the flight muscles are attached to the sternum. *B*, comparison of the wing of a chicken with that of a hawk. Note the relative length of the bones that determine the area of wing spread. *A, modified from Lucas.*

gelatinous network composed of the secretion of its salivary glands. These nests are considered quite a delicacy and are collected and sold, the price depending upon the purity of the materials in the nest. The nests are made into soups, jellies and other dishes.

Birds are highly specialized animals. In fact their specialization has reached such a degree that they are considered racially old. Thus we find sharp-hooked beaks and curving grasping talons on the birds of prey (Fig. 312). Swimming birds have webs between the toes. The wading birds have long slender legs and toes which enable them to walk on soft muck. Their beaks may be long and slender, thus facilitating search through the mud for larvas and other food. The hummingbird has a beak specially adapted for gathering nectar. One of the most generalized birds is the English sparrow. It eats probably all types of food and lives in any environment. Generalization in structure has enabled it to survive and

adapt itself to many varied conditions. In adaptability the European starling is a close second to the English sparrow.

Specialization of structure also occurs in the nervous system of birds. We find a very highly developed cerebellum, which, it will be remembered, is the center of muscular correlation and reflex action. Since the cerebrum or thinking organ does not appear to be so well developed, it is doubtful that birds rank very high in intelligence. Many of the bird's responses seem to be of the reflex type. Birds have a poor sense of smell but make up for it by their keen vision, their eyes being capable of remarkable adjustments for near and far sight. Thus the vulture does not smell his meal but detects the dead animal by its position and lack of motion.

The largest modern bird is the ostrich. An ostrich may reach a height of eight feet and weigh more than three hundred pounds. Ostriches do not fly but depend upon running and blows of their long legs for protection. Contrary to popular belief, they do not hide their heads in the sand. Because the plumes are valuable to man, ostrich farming is a large industry. The industry is especially large in Africa, and there are some farms in the United States. It is estimated that there are 500,000 tame ostriches on the African ostrich farms. These birds are worth between \$700 and \$1,000 a pair. Each bird produces annually about \$15 or \$20 worth of plumes. Other flightless birds, not related to the ostrich, are the emus, cassowaries, and penguins. Penguins have short paddle-shaped wings adapted for swimming. They spend the greater part of their lives in the ocean and are graceful swimmers, but on land they walk awkwardly erect or slide along on their bellies.

Several penguins may form a partnership for incubating their young. The eggs are laid during the long antarctic night, only one to a female. After an egg is laid, it is rolled on top of the bird's foot, and a flap of loose skin folds over it to protect it and incubate it. When the bird is tired of carrying the egg thus, it rolls it off the foot, and immediately a number of others rush up to gain possession of it. Both males and females participate in this transference of eggs, and when finally hatching occurs the egg is as likely to be in the custody of a male as of a female.

The various kinds of ducks and geese with their webbed feet, flattened bills, and aquatic habits are grouped into one order called the Anseriformes (gooselike birds). They are very useful as food and are hunted quite extensively.

Birds of prey, such as hawks and eagles, are related and have a bad name as killers of other animals valuable to man. But the vultures are valuable as scavengers, and not all hawks are our ene-

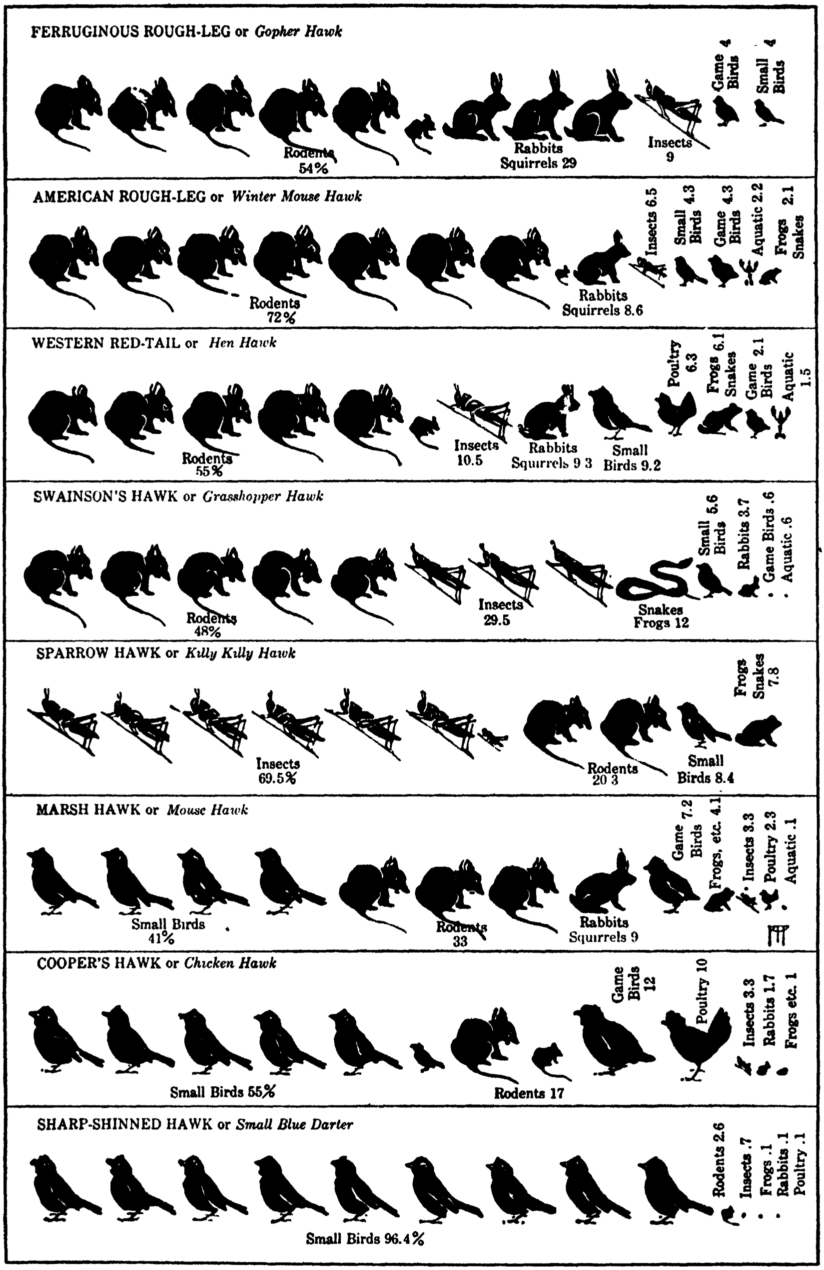


FIG. 274. Chart showing the food of various hawks. Note that insects and rodents furnish the bulk of the diet of most of the hawks. *Chart furnished by the National Association of Audubon Societies.*

mies (Fig. 274). The little sparrow hawk kills very few birds but feeds mostly on mice and insects. Often owls are placed among the birds of prey. Owls come in for much abuse, especially from the so-called sportsmen, who blame them for killing other birds and young game which they wish to kill for sport but which wild animals have to kill in order to live. With the exception of the great-horned owl, owls feed extensively on rodents. We have no better friend than the little screech owl, and the monkey-faced owl or barn owl is extremely useful as a rodent destroyer. Surprisingly enough, the near relatives of the owls are kingfishers, hummingbirds, and woodpeckers. The woodpeckers deserve honorable mention, for they search out and destroy various insect larvas and beetles hiding under and in the bark of trees. They cling to the tree by their long claws, propping themselves by their stiff tail feathers, and drill with their drill-like beaks for the insects hidden beneath. The insect or grub is impaled on the tongue and eaten.

The birds most familiar to us—sparrows, thrushes, warblers, and crows—are called passerine birds (Passeriformes) or sparrowlike birds. They are mostly of medium size and have feet adapted for perching. Almost all the birds of this group feed on insects or weed seeds and thus are of inestimable value to man. They should be protected and encouraged in every way.

We cannot exaggerate the importance of birds to man. They serve for food and are the guardians of our food supply. They are our allies in our war with the insects. A hawk or an owl may steal an occasional chicken or rabbit, the robins and blackbirds may pick a few cherries, but, in comparison, the help they give makes such depredations a very minor matter.

Class Mammalia (*mamma*—breast). Mammals are distinct from other vertebrates in that they are covered with **hair** at some period in their life, have **mammary** or milk **glands,** and suckle their young. Mammals are **warm blooded** and have hearts made up of two auricles and two ventricles. The chambers on the right side of the heart are completely separated from those on the left. The red corpuscles are round and non-nucleated.

Most mammals are viviparous, but a few primitive ones lay eggs. Most mammals have small, almost microscopic eggs containing very little yolk. The young develop within the uterus, with which they are in more or less intimate contact by the **placenta,** which is characteristic of mammals only. An amnion and an allantois are present, but the allantois is sometimes rudimentary. The egg-laying habits of the primitive mammals as well as certain of their anatomical

characters seem to indicate that mammals are descendants of reptilian ancestors. Man, of course, is a mammal. There are many orders in the class, but we shall consider only the most important and interesting of them.

ORDER MONOTREMATA (*monos*—one; *trema*—hole). These are primitive, egg-laying mammals of the Australian Archipelago. Besides the egg-laying habit, they have other reptilian characters such as a cloaca into which empty the two oviducts, the intestine, and the urethra. In other mammals the genito-urinary opening is separate from the intestinal opening. These and other reptilian characters have led some zoologists to dub the monotremes the "missing link" between reptiles and mammals. The very primitive mammary glands pour their secretions on the hair of the abdomen, from which it is licked by the young animal. The duckbill and the spiny anteater are monotremes. The duckbill not only lays eggs but also has a toothless, flattened bill and webbed feet.

ORDER MARSUPIALIA (*marsupium*—a pouch). The marsupials are mammals which carry their young in a ventral abdominal pouch. Included in this group are the opossums of North America and the kangaroos, pouched moles, and other animals found in Australia. The young of these animals are born in a very immature condition and are placed within the pouch where they are anchored to the teats by their mouths. The flesh of kangaroos and opossums is edible, and the hide of the kangaroo makes very good leather.

ORDER INSECTIVORA (insect; *vorare*—to devour). This group of small moles and micelike shrews feeds almost exclusively on insects, insect larvas, and earthworms. The common mole is entirely subterranean in its habits. It often excavates its long tunnels just under the surface of the ground, and the rounded roof sticks up above the general surface. This does not look well on a smooth lawn, but we must remember that the mole is seeking insect pests and their larvas. The mole shows interesting adaptations to its mode of life. The eyes, useless underground, are very rudimentary and have almost disappeared, and the front feet have developed into broad, handlike structures which enable a mole to burrow through the ground at a rapid rate. Except as insect destroyers moles have little value, although they have been eaten as food.

ORDER CHIROPTERA (*cheiro*—hand; *pteron*). Chiroptera are bats, the only true flying mammals. The fingers and arm bones of bats are exceedingly long, and between them, and to the tail and hind legs, extends a membrane forming a wing. Bats vary in size from a wing spread of only a few inches to one of five feet in the tropical

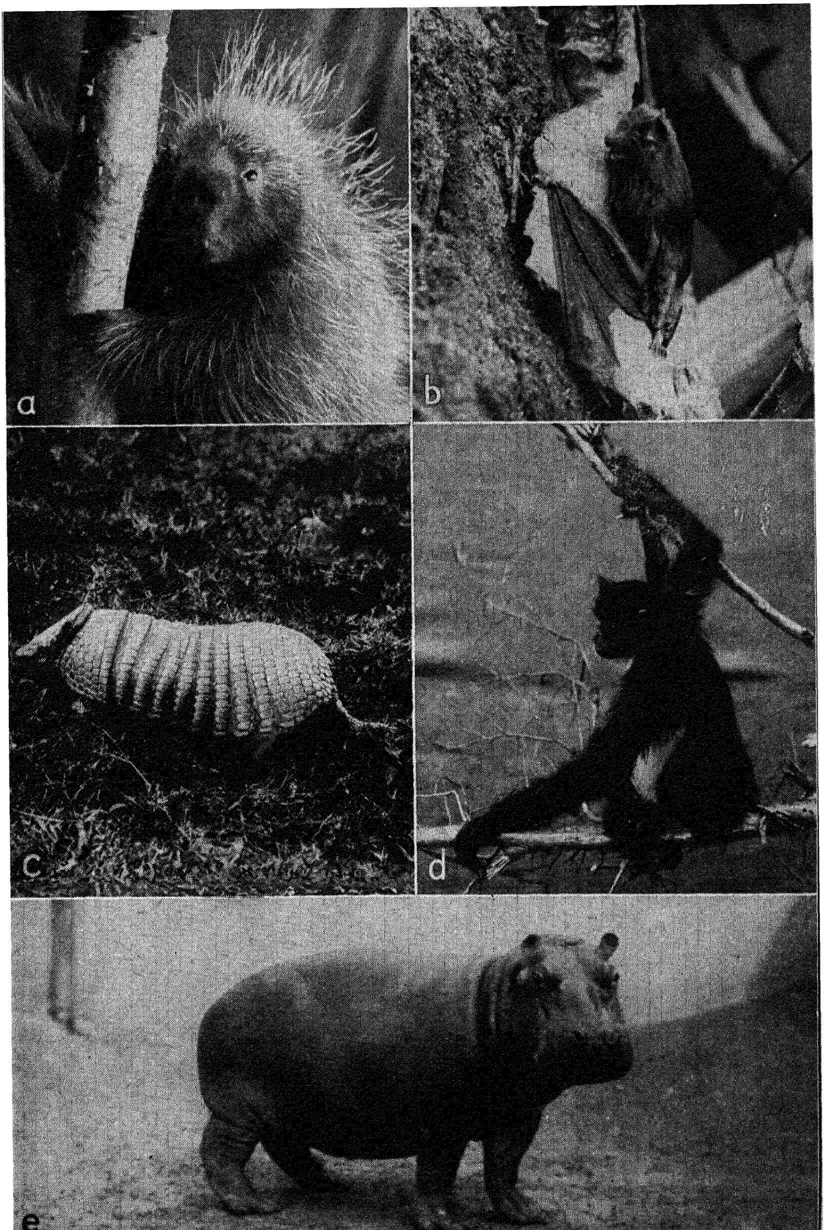


PLATE XVIII. Mammals. (Class Mammalia.) *a*, Canadian porcupine; *b*, little brown bat; *c*, armadillo; *d*, spider monkey; *e*, hippopotamus. *Photographs: a furnished by the Fish and Wildlife Service (Spencer); b, R. L. Fricke, Carnegie Museum; c and e, National Zoological Park; d, New York Zoological Society.*

forms. Bats, as is well known, sleep during the day and work at night. Usually a number of them occupy the same roost. These nocturnal animals amaze us by their ability to avoid objects in their swift flying through the darkness. They seem to have a very keen sense which enables them to detect their approach to an object by the perception of supersonic waves which they have initiated. A bat whose eyes had been blinded flew about in a darkened room through which a number of strings had been stretched and did not hit any of them.

Our bats here in America carry on the work of insect destruction at night and the birds continue the job during the day. They are our benefactors and friends. They do not carry bedbugs and do not get tangled in women's hair! In the Orient and the tropics there are large fruit-eating bats. The vampire bats of South America attack domestic and other animals and suck their blood. A few isolated attacks on man have been reported.

ORDER CARNIVORA (*caro*—flesh; *vorare*). Most Carnivora are flesh eaters, but, as usual, there are some exceptions. The Carnivora have small, weak incisor teeth and sharp, curved canines, or eyeteeth, with which they grasp and tear their prey; the cutting premolars and grinding molars complete the job.

This is an interesting and important order numbering among its members lions, tigers, bears, dogs, and wolves, as well as many valuable fur-bearing animals such as minks, martens, skunks, otters, seals, and foxes. In 1943, Alaska yielded 117,164 fur-seal skins. At two public auctions in St. Louis, 38,655 fur-seal skins were sold for a gross sum of $1,738,002.35. Many people are engaged in fox farming, and skunks, minks, and similar animals are raised on farms.

Some of the Carnivora are very destructive to livestock and the bigger game animals. On the western ranges, in one year the livestock destroyed by wolves, coyotes, and other predatory animals were valued at $20,000,000. Nor should we fail to mention the house cat as a predatory carnivore. It is estimated that a cat kills ten to fifty birds in a year. If cats should average only ten birds per year, the estimated kill for Massachusetts alone would total about 700,000 birds!

ORDER RODENTIA (*rodo*—I gnaw). Rodentia comprise a group of familiar animals including rats, mice, beavers, muskrats, ground hogs, squirrels, rabbits, and others. They do the chiseling and gnawing with their sharp, chisel-like incisor teeth, which continue to grow as the cutting end is worn away. The canine teeth are missing. The

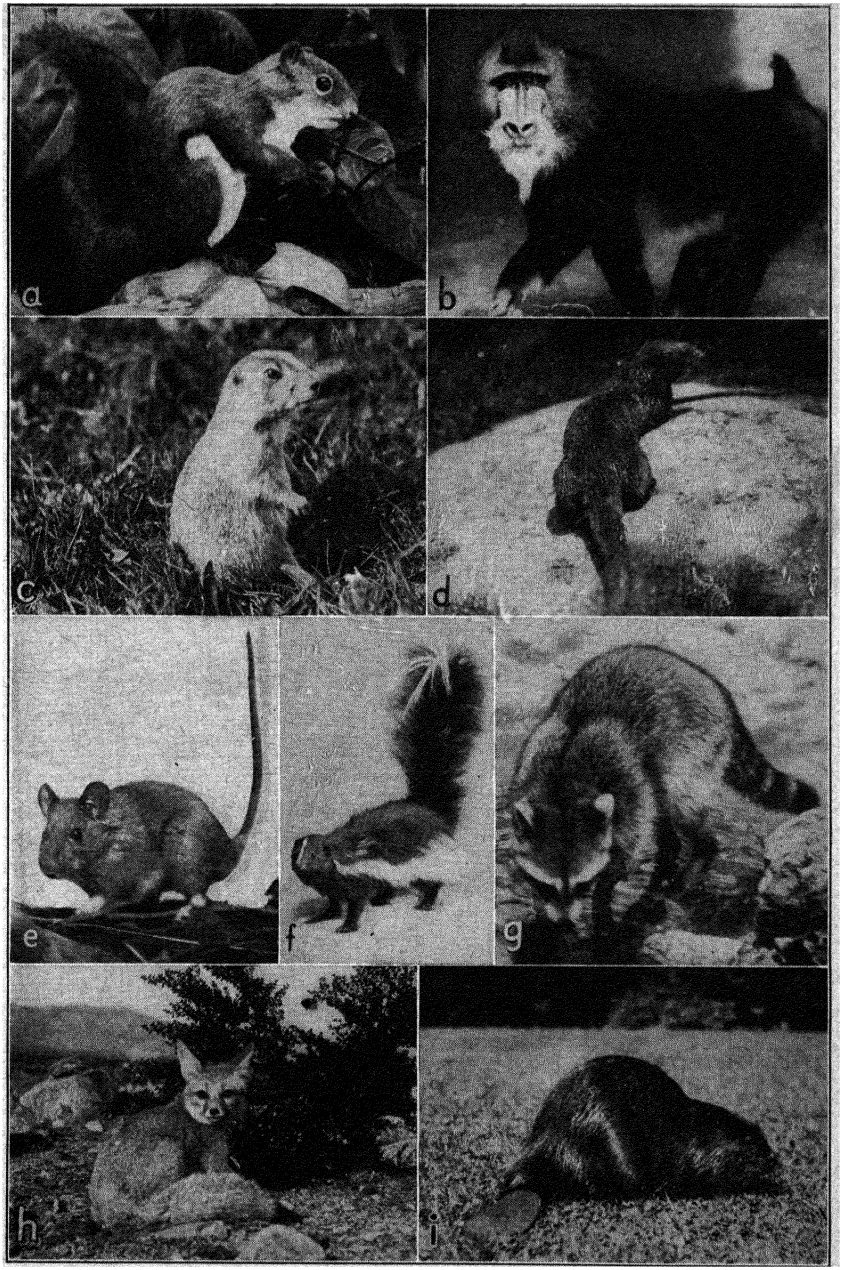


PLATE XIX. Mammals. (Class Mammalia.) *a,* squirrel; *b,* mandrill; *c,* prairie dog; *d,* otter; *e,* wood rat; *f,* skunk; *g,* raccoon; *h,* desert fox; *i,* beaver. *a, c, and e furnished by R. L. Fricke, Carnegie Museum. b, furnished by the New York Zoological Society. d, furnished by the National Zoological Park. f, g, h, and i furnished by Fish and Wildlife Service, U. S. Department of the Interior.*

rodents are the most typical of all mammals, very prolific, and readily adaptable.

Beavers and porcupines are very interesting rodents. Beavers live along streams. They fell large trees and make dams which often cause considerable areas to be flooded, and at the same time such flooded areas afford a sufficient water level to cover and protect the entrances to their burrows. Porcupines are interesting because of their defense mechanism of sharp, penetrating quills which prick the attacker when he comes in contact with them.

The "personal" habits and the losses inflicted by rats and mice are well known. The United States Biological Survey estimates that in one year rats alone may cause losses amounting to $200,000,000. Moreover, rat fleas carry bubonic plague. Rats have been blamed for carrying other diseases, but the case is not closed as yet. The common rat of most localities is the brown or Norway rat. Mice are household pests, and field mice do enormous damage to growing crops. In Nevada, from 1906 to 1908, meadow mice ruined the alfalfa crop on 18,000 acres. Rabbits and mice will girdle fruit trees and thus ruin orchards. Rabbits, squirrels, and ground hogs are eaten quite extensively, and rabbit skins are tanned and used in the preparation of furs. One of the most important fur-producing animals in America is the muskrat.

Order Artiodactyla (*artios*—even; *daktylos*—toe). Animals of this order are cattle, pigs, deer, camels, hippopotamuses, giraffes, and others. They are even-toed, hoofed animals having two functional toes with well-developed toenails or hoofs. Thus a cow or a pig actually walks around on the toenails of two toes on each foot! Two splints of other toes are often present but are not used by the modern representatives. Many of the Artiodactyla such as cattle and deer are known as ruminants or cud-chewers. In the wild state the cud-chewers depend mostly upon speed for protection, so they crop their meal of grass or herbage in haste and send it down to the first two stomach compartments for storage. This material is later returned to the mouth, chewed thoroughly, and then swallowed to pass into the last two stomach chambers—there are four in all—where digestion continues. Digestion is finally completed in the intestine.

The food value of most of the species of this group is very well known. Reindeer have been domesticated for a long time in Lapland and were introduced into Alaska about 1892. The animals, distributed among specially trained Eskimos, number about 712,000.

Reindeer furnish food and leather and are useful in transportation. In one year, almost half a million pounds of reindeer meat were exported from Alaska to the United States.

Camels have been domesticated since the earliest times. They are useful as beasts of burden, their hair is woven into cloth, and camel

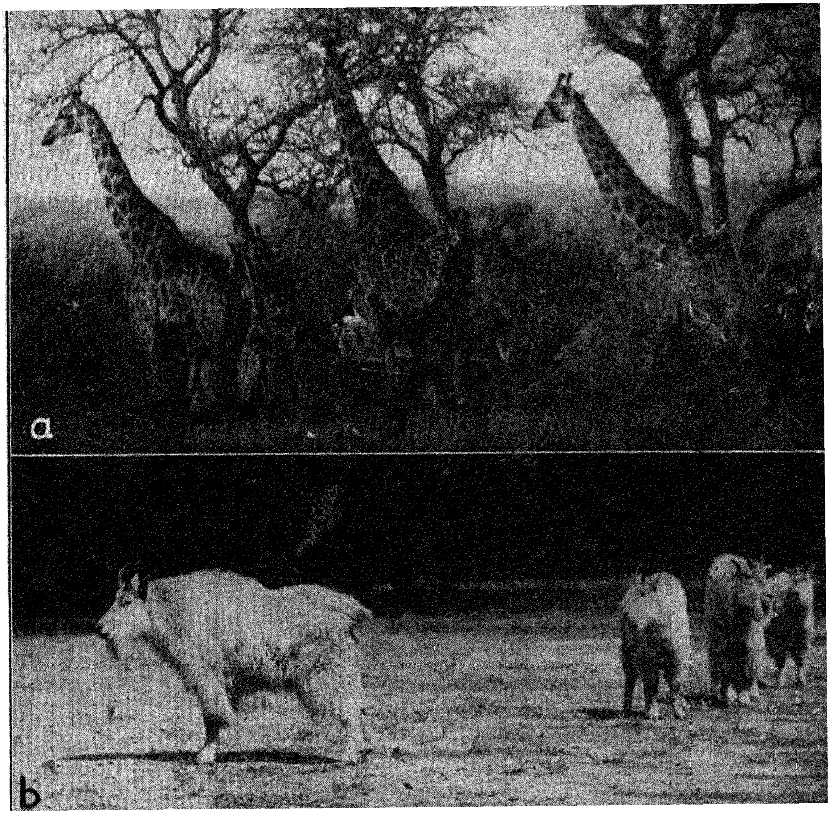


PLATE XX. Mammals. (Class Mammalia.) *a*, giraffes; *b*, Rocky Mountain goats. *Photograph a furnished by Publicity Department, South African Railways and Nature Magazine; b furnished by the National Zoological Park.*

milk is used as food. Camels are well fitted for desert traveling; their feet are soft-padded, and their nostrils can be closed against the sand. Moreover, they can provide nourishment and water during long journeys, for they are able to store food in the humps on their backs and fifteen or twenty quarts of reserve water in small saccular compartments of the stomach. Each compartment is closed off by a muscle. "One celebrated traveler mentions the case of a

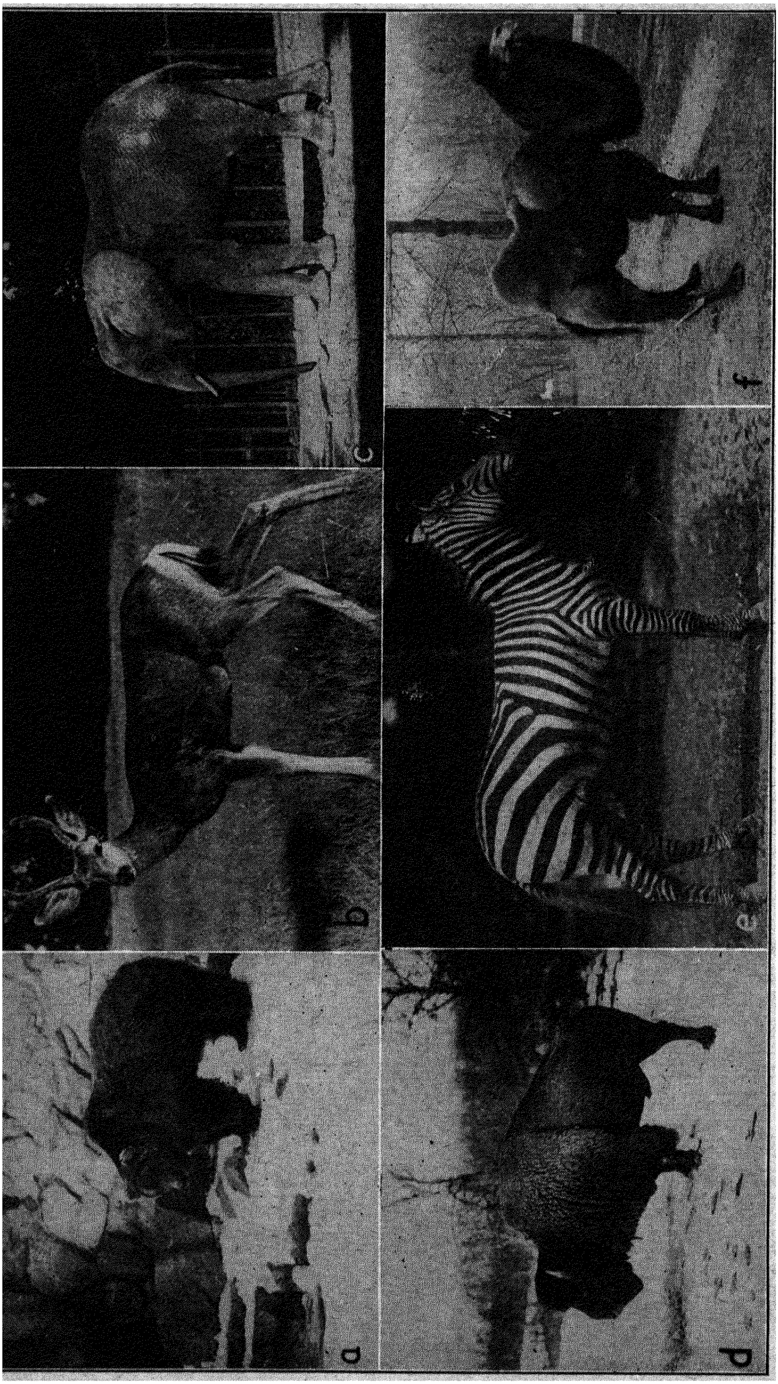


PLATE XXI. Mammals. (Class Mammalia.) *a*, grizzly bear; *b*, Virginia or white-tailed deer; *c*, African elephant; *d*, bison; *e*, zebra; *f*, camel. *Photographs a, c, d, e, f furnished by the National Zoological Park; b furnished by R. L. Fricke, Carnegie Museum.*

camel that had been dead for ten days and yet had no less than three pints of not unpleasant water remaining in his stomach."

Order Perissodactyla (*perissos*—odd; *daktylos*). Perissodactyla are odd-toed, hoofed animals such as horses, zebras, tapirs, and rhinoceroses. Horses gallop and prance about on the toenail (hoof) of the sole remaining toe on each foot. The present horses are apparently descendants of Asiatic ancestors. The wild horses of the western plains are not native but are descendants of horses brought here by the early Spanish explorers.

Order Proboscidea (*pro*—before; *bosco*—feed). Elephants live in Asia and Africa. The elongated trunk is the nose, and the tusks are the modified and greatly elongated incisor teeth of the upper jaw. The Asiatic elephant, being more intelligent and better tempered, is seen most often with circuses and is the beast of burden in many countries.

Order Primates (*primus*—first) include lemurs, monkeys, gorillas, apes, and man. With the exception of man, primates are most plentiful in the warmer parts of the world. Man is found in all regions. Primates have nails instead of hoofs and claws. Usually only one offspring is born at birth. As far as the skeleton is concerned they are not so highly differentiated, but in intelligence they lead all animals.

The lemurs have rather long tails. They are aboreal and resemble squirrels as they flit through the tree tops in Madagascar. Apes and monkeys are also tree-living forms. The new-world monkeys have widely separated nostrils, but the old-world monkeys and apes have nostrils rather close together and directed downward. The tail of the old-world monkeys and apes is very small and sometimes even rudimentary. The highest primates are the gibbon, orangutan, gorilla, chimpanzee, and man. Gibbons have arms so long that they can touch the ground even when standing erect. The orangutan builds a nest in the trees and is somewhat retiring. The gorillas and the chimpanzees are mostly fruit and vegetable feeders and live in herds. It may be interesting to know that in intelligence the chimpanzee is more closely related to man than the gorilla is, whereas from the anatomical standpoint the gorilla is the more closely related.

Order Cetacea (*ketos*—whale). There are various types of whales, dolphins, porpoises, and narwhals. Like some of the reptiles, these mammals apparently were originally land forms which have taken to the water. The fore limbs have been modified into flippers, and the pelvic appendages have practically disappeared. Some of

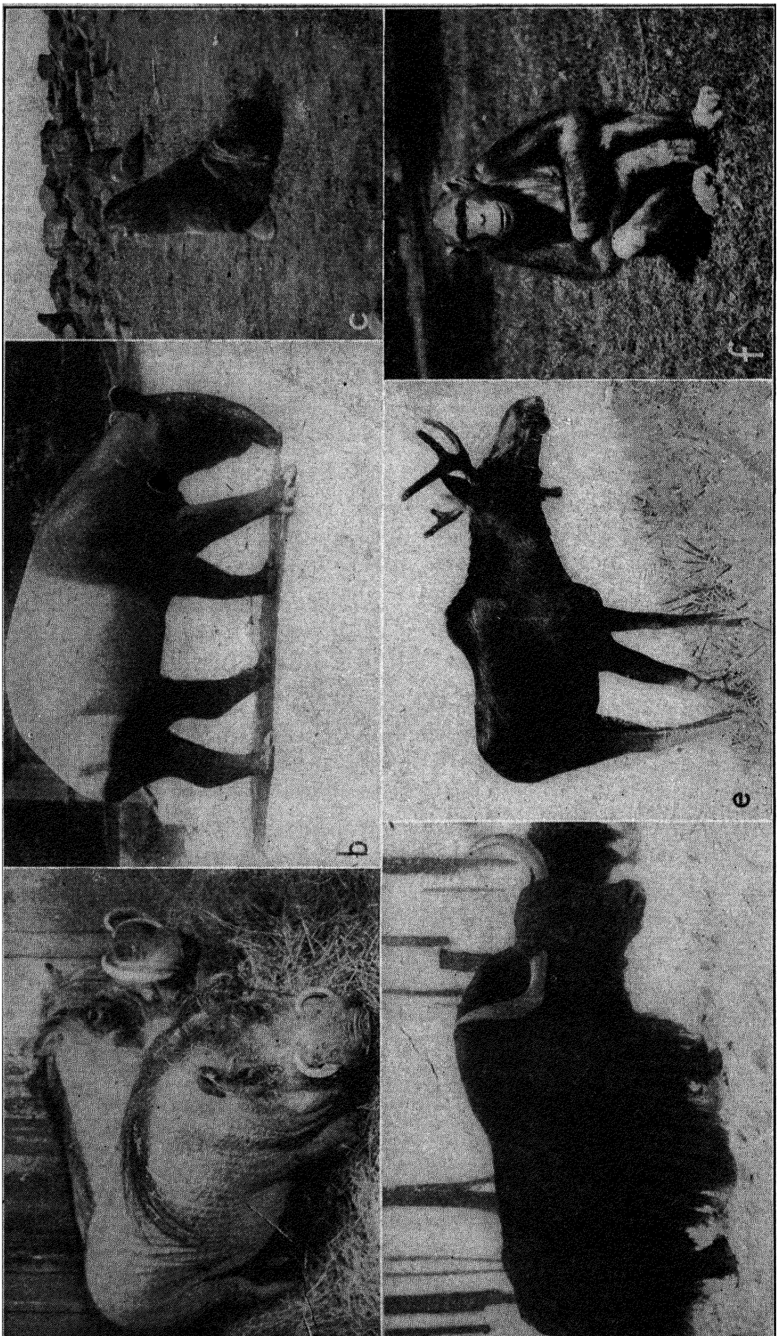


PLATE XXII. Mammals. (Class Mammalia.) *a*, northern wart-hog; *b*, Malay tapir; *c*, young bull fur-seal; *d*, yak; *e*, moose; *f*, chimpanzee. *Photographs a, b, d, e, f furnished by the National Zoological Park; c furnished by* ***Fish*** *and* ***Wildlife*** *Service,* ***U. S.*** *Department of the Interior (Carr).*

the cetaceans are the largest mammals—in fact, they are the largest living animals and rival the dinosaurs in both size and bulk. One species reaches a length of a hundred feet and may weigh as much as 300,000 pounds. The old whaler's cry of "thar she blows" is heard when a whale is seen spouting a cloud of spray and vapor from its nostrils as it comes to the surface after a dive. Some of the whales have well-developed teeth, but the upper jaws of the whalebone whales are equipped with numerous frayed horny strips which, collectively, are known as baleen or whalebone. The strips of whalebone may be ten or twelve feet in length. When feeding, the whale gulps a large mouthful of water and then strains it out between the horny strips. Naturally, most of the living organisms in the water are retained in the mouth and swallowed.

Whales are hunted to obtain not only the whalebone or baleen but also whale oil. One whale will yield as much as 3,000 pounds of baleen, worth from five to six dollars a pound, and about 300 barrels of oil. Ambergris, secreted by the intestine, is a solid comparable perhaps to gallstones of other animals. It sells for about five to ten dollars per ounce. It has been used in making perfumery and also in medicine.

Other Orders of Mammalia. We have tried to present the most interesting and important orders of Mammalia. There are other orders in this class which can be studied in detail in various books of zoology and natural history.

CHAPTER XV

THE PLANT KINGDOM. WHAT ARE THALLOPHYTES AND BRYOPHYTES?

PHYLUM THALLOPHYTA

(*thallos*—young shoot; *phyton*—plant)

The first phylum of the plant kingdom is Thallophyta. The term **thallus** designates a plant body that has no true roots, stems, or leaves. In some of these plants, notably the seaweeds, there are structures that superficially resemble roots, stems, and leaves, but such structures are not characterized by the differentiation of tissues found in the vegetative organs of the higher plants. In contrast to the multicellular sex organs of higher plants, the sex organs of thallophytes are mainly one-celled structures. Later, we shall discover that some thalloid plants occur in other phyla but the simplest forms are found in this first group. Thallophytes are plants of very diverse character, ranging from microscopic bacteria to the giant kelps of the Pacific coast, which reach a length of 150 feet. Of this phylum we shall consider only the **Fungi** and the **Algae.**

ALGAE

The name alga means seaweed, but algae are found in both marine and fresh waters. They are typically aquatic plants and, with very few exceptions, contain chlorophyll. Some species grow on the soil; others grow on rocks or tree trunks. Small floating forms mixed with tiny aquatic animals sometimes accumulate in enormous quantities in the upper levels of the water. Such an assemblage is called **plankton.** Algae are extremely important since they constitute the primary food supply for all aquatic animal life. But the presence of these plants is not always an unmixed blessing. When certain species accumulate in large numbers in our water supply, especially in reservoirs, their decomposing bodies liberating essential oils impart very objectionable odors and flavors to the water. The problem has given the waterworks engineers considerable trouble.

Concerning the total number of algal species there would doubtless be little agreement among the authorities, but it is quite certain that there are more than 20,000 species of these plants. We have mentioned only a few of the more common forms. As compared with seed plants, this group has very little direct economic importance but holds first rank as a basic food supply for aquatic animals. Algae also have very great importance from the strictly scientific viewpoint in showing how more complex plants may have arisen from simple ones, and how reproductive structures and processes may have developed from simple beginnings.

The algae run the whole gamut of reproductive behavior. In the simplest forms reproduction involves only simple cell division. In more highly specialized forms, the protoplasts are broken up to form spores, quite commonly motile spores or **zoospores,** which germinate to form new plants. In many species gametes are produced and sexual reproduction takes place. Heavy-walled vegetative cells, called "resting spores," are often encountered in this group; they serve to carry the species through periods of unfavorable conditions such as drought and extreme temperatures.

In certain algae the chlorophyll is masked by other pigments so that the plants do not appear green. Partly on the basis of this color difference, but mainly by reason of differences in vegetative structure, reproductive structures, and behavior, the algae are divided into four principal groups.

The Myxophyceae (*myxo*—slime; *phykos*—seaweed). These plants may occur as water plants or as slimy patches on soil or rock. They are essentially unicellular plants of extremely simple organization—the simplest of all algae. *Gloeocapsa,* for example, is a microscopic cell with a cellulose wall enveloped in a gelatinous sheath secreted by the cell (Fig. 275). The cell contains neither nucleus nor chloroplast. The chromatin material and the chlorophyll are dispersed throughout the protoplast which has a bluish green color. The bluish tint is caused by a blue pigment, **phycocyanin** (*phykos*—seaweed; *kyanos*—blue). The cell reproduces by simple fission only, and the gelatinous sheath holds the daughter cells together so that colonies of two, four, eight, or more cells are quite common. The secretion of mucilage and the consequent tendency to form colonies are characteristic of the members of this group. In *Merismopedia,* the cell divisions are restricted to two directions in a single plane so that the resultant colonies have the form of plates with the thickness of a single cell (Fig. 275). In *Nostoc* and *Anabaena,* the divisions are restricted to one direction in a single plane, and the resultant

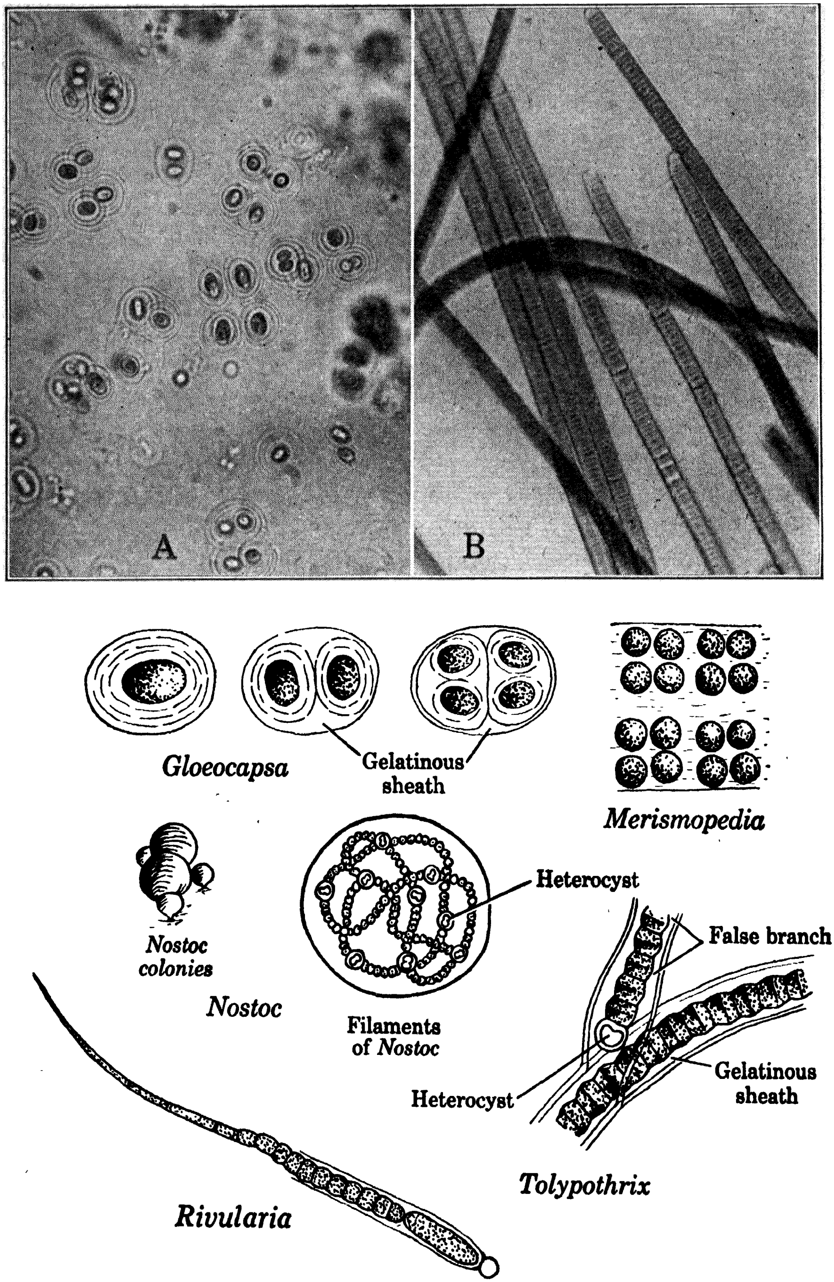


FIG. 275. Types of Myxophyceae. *Photomicrographs A and B furnished by the General Biological Supply House.*

colony is a filament (Fig. 275). In *Nostoc,* there is a very heavy gelatinous sheath and many sheaths cohere to form jellylike globules that may attain the size of a walnut or even of a small orange. In *Oscillatoria* (Fig. 275), the cells of the filament seem to have developed a slight degree of coordination, for when observed under the microscope the filaments are seen to perform a swinging, revolving movement.

There are many other forms of blue-green algae, and the group has a wide distribution in fresh, brackish, and marine waters. One form containing a red pigment, when present in large numbers, imparts a red color to the water—a fact responsible for the name of the Red Sea. Certain species constitute the principal vegetation of hot springs and geyser basins, where they thrive at temperatures as high as 87° C.

The brightly colored rock basins of the Yellowstone National Park are explained by the fact that the algae become encrusted with minerals extracted from the water. It has been reported that some blue-greens have remained alive in samples of dry soil for fifty to seventy years. This high degree of resistance to heat and desiccation has not yet been satisfactorily explained, but doubtless the water-retaining capacity of their gelatinous walls, together with some peculiar organization of the protoplasm, is involved.

The blue-greens probably have considerable value as soil formers, especially those occurring in the lichens, which we shall study later. As one of the important components of plankton they furnish food for aquatic animals. Aside from these two roles, the blue-greens are of little or no positive economic importance, and too frequently they become troublesome weeds on greenhouse soils. They also become a nuisance in reservoirs where water is stored for domestic use.

The Chlorophyceae (*chloros*—green; *phykos*). These are more highly specialized than the blue-greens, for all the plants of this group have chloroplasts and well-defined nuclei. They are abundant in the warmer waters of the ocean and in the lakes, ponds, and streams of the temperate zone. One species (*Sphaerella nivalis*) is responsible for the patches of red snow sometimes observed in arctic and alpine regions. Green algae also occur on rocks, on tree trunks, and in the soil. Some simple forms are always found in the bodies of certain of the lower animals, and one species (*Chlorella*) lives within the endodermal cells of the green hydra! The plants of this group display a great diversity of form and structure, ranging from simple unicellular algae through multicellular branching filaments and broad sheets to gelatinous masses.

One of the simplest of the green algae is *Protococcus* (Fig. 276). This unicellular alga, growing singly and in loose colonies, forms the green "paint" that is so commonly observed on tree trunks, fence posts, and rocks. Each plant is a rounded green cell containing **cytoplasm** and a **nucleus.** In the cytoplasm there is imbedded a large **chloroplast** that almost fills the cell. The cell wall is usually quite thick. Apparently these plants reproduce by simple fission only.

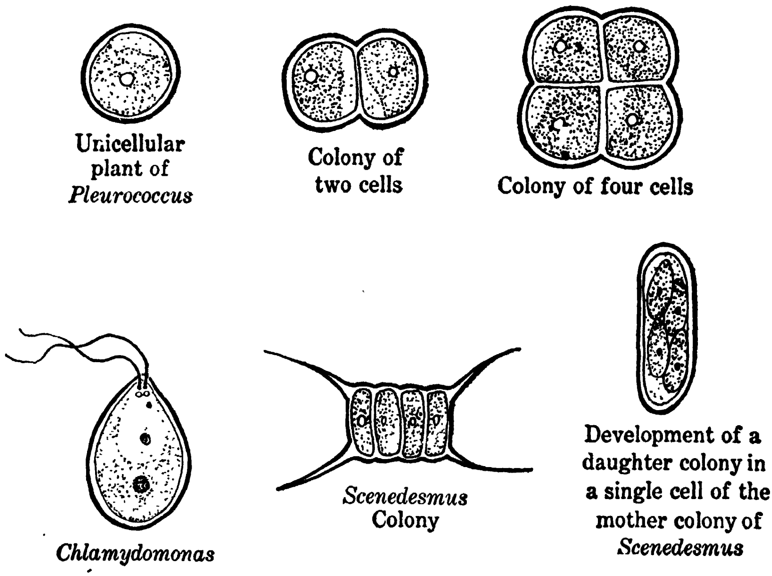


FIG. 276. Types of Chlorophyceae.

Chlamydomonas, unlike *Protococcus,* is a free-swimming plant. It may be found in the water of ponds and ditches and is frequently observed in a green scum on the surface of stagnant pools. At the anterior end of the cell are two **flagella,** the agents of locomotion. At the base of the flagella are two **contractile vacuoles,** and in the same general region there is a **red pigment spot.** There is a single large cup-shaped **chloroplast** in the bottom of which lies a **pyrenoid** that serves as a center of starch formation. Reproduction takes place by the formation of resting cells, zoospores, and gametes. Here we see a beginning of sexual reproduction in plants. *Volvox* is a hollow, spherical colony consisting of thousands of *Chlamydomonas*-like cells so arranged that the ends bearing the flagella are directed outward. The concerted lashings of these flagella cause the globular colony to go rolling through the water.

Chlamydomonas and *Volvox* belong to a class of organisms known as the *Flagellata.* As previously noted, zoologists consider these organisms animals and give them a place among the Protozoa. Here we see that the botanists consider them algae. Such differences of opinion merely stress the fact that among the lower organisms there is no sharp line of demarcation between plants and animals. Some flagellates manufacture their own food, as do all the green plants. Other flagellates engulf solid food particles, a food habit common to animals generally. But, regardless of these differences, all these forms are clearly bound together by both structural and physiological characteristics.

No other groups of green algae have motile vegetative cells. Henceforth, throughout the plant kingdom, the vegetative cells are stationary and only zoospores and sperms are capable of locomotion. *Spirogyra* (Fig. 137) has no motile cells of any kind. This is an unbranched, multicellular, **filamentous** plant. According to the species, each cell contains one or more chloroplasts. The chloroplast is a spiral, green ribbon studded with pyrenoids. Only sexual reproduction occurs in this alga, and the process has already been described. (See page 259.) The cell formed by the fusion of two protoplasts is called a zygote. The zygotes develop into heavy-walled cells that sink to the bottom. If the pool dries up, these cells can endure desiccation for a long time, and, when favorable conditions return, each may germinate and give rise to a new plant.

The possible evolution of reproductive behavior can be best observed in another filamentous green alga called *Ulothrix* (Fig. 137). Here an ordinary vegetative cell may undergo multiple division producing four to sixteen flagellate zoospores. When these finally escape from the cell, they may swim about for several days, after which each one attaches itself by the flagellated end to a stone or other object It now loses its flagella, develops a cell wall, and, by divisions and enlargement of the new cells, grows into a new filament. However, the protoplast of any vegetative cell may continue dividing until thirty-two to sixty-four small, biflagellate gametes are formed. A plant that produces gametes is called a **gametophyte.** The nuclei in the cells of the gametophyte contain the n number of chromosomes. When the gametes escape from the cell, they swim about for a time until they meet gametes from other filaments, with which they fuse in pairs to form zygotes. Each zygote soon loses its flagella, comes to rest, and develops a heavy wall. It then remains dormant during the period of unfavorable conditions, and when a favorable environment is restored the zygote may germinate, giving rise to

a number of zoospores which subsequently grow into new plants. Here we see no suggestion of sex organs and no apparent differences between the gametes. It will be recalled that such sexual reproduction involving the fusion of like gametes is known as **isogamy.**

In another filamentous green alga, *Oedogonium* (Fig. 277), some of the vegetative cells form **zoospores,** just as they were formed in *Ulothrix.* However, other vegetative cells may enlarge through accumulation of food and function as gametes. Since they have the food supply and are stationary, they are the **eggs,** and the cells pro-

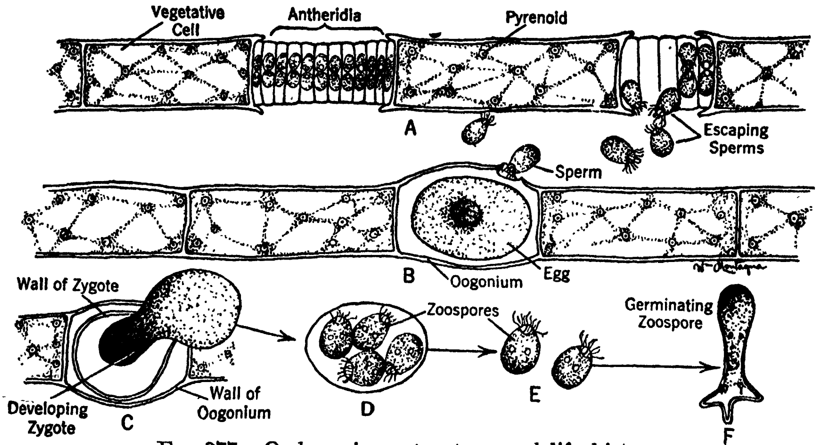


FIG. 277. *Oedogonium,* structure and life history.

ducing them are the **oögonia** or female sex organs. Other vegetative cells divide to form several **antheridia,** or male sex organs, in each of which two sperms are developed. The sperms escape and finally swim through an opening in the wall of the oögonium, where one sperm unites with the nucleus of the egg, forming a zygote. The zygote develops a heavy wall and remains dormant for a time, after which it germinates and produces four zoospores, each of which may give rise to a new plant. In this alga we see a differentiation of sex organs and also a differentiation of gametes. Such sexual reproduction involving the fusion of unlike gametes is known as **heterogamy.** In some species of *Oedogonium,* both antheridia and oögonia are borne in the same filament, but in other species a given filament produces only one kind of sex organ. Where the two kinds of sex organs occur in different filaments, there is a differentiation of male and female plants. Thus in the development of specialized sex cells, specialized sex organs, and specialized sexual individuals, *Oedogonium* outlines the possible evolution of sex in the biological world.

In *Oedogonium* the nuclei of the cells of the vegetative plant contain n chromosomes, and since meiosis does not occur in the formation of the gametes the nucleus of each gamete contains n chromosomes. The union of two gametes forms a zygote with $2n$ chromo-

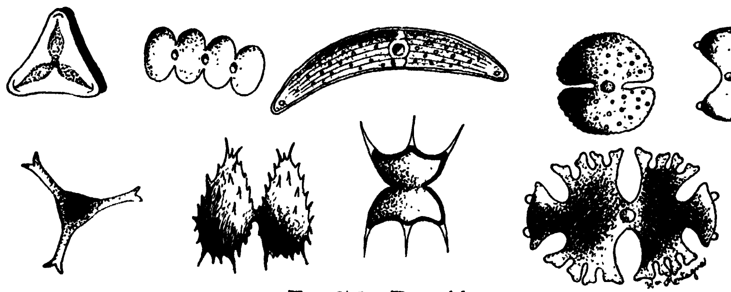


FIG. 278 Desmids.

somes. In *Oedogonium*, the zygote undergoes meiosis, forming two cells each having n chromosomes; hence the cells of the young plant will have n chromosomes. This means that $2n$ chromosomes are found in the zygote only. Since plants whose cells contain $2n$ chro-

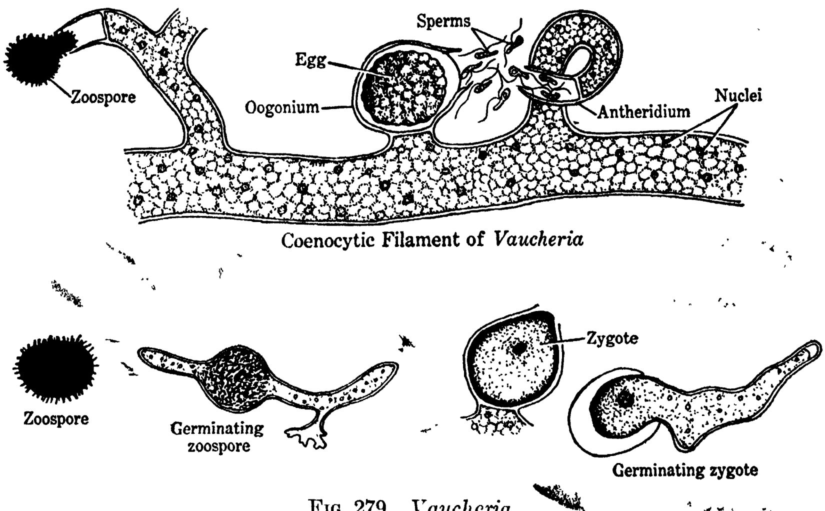


FIG. 279. *Vaucheria*.

mosomes are known as **sporophytes,** we can readily see that no sporophyte occurs in this group; and the gametophyte manufactures the food and carries on all reproductive activity.

There are many other kinds of green algae. The **desmids** are beautiful, unicellular algae that present an almost infinite variety of design (Fig. 278).

Cladophora is a coarse, branching form widely distributed in swift-flowing streams, where it grows attached to the rocks. *Vaucheria* is found in pools and ditches and on moist soils (Fig. 279). It is also a troublesome weed in greenhouses, where it often forms a green felt on the surface of the moist soil, especially when it has not been disturbed for some time. The branching filaments of *Vaucheria* have no cross walls and are therefore **coenocytic** organisms; that is, they have many nuclei with no walls between them. *Chara,* a member of the so-called stoneworts, and one of the most highly organized members of this group, in appearance resembles somewhat a small seed plant (Fig. 280). Enormous numbers of these stoneworts grow from the ooze at the bottom of shallow ponds and lagoons and become encrusted with calcareous sheaths. Eventually the pond may disappear and subsequently the bed may be excavated to obtain the marl consisting mainly of the accumulated calcareous remains of these algae, valued so highly as a fertilizer.

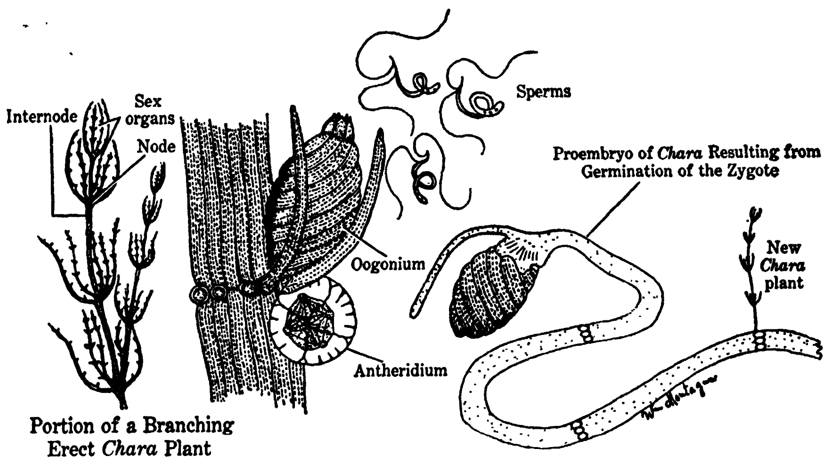


FIG. 280. *Chara,* a complex green alga.

Green algae furnish much of the food of fish and other aquatic organisms. In certain countries, some of the species form a part of the human diet. Like the blue-greens, certain green algae when growing in reservoirs often impart undesirable odors and flavors to the water, confronting water-works engineers with numerous problems. The algae can be eliminated by adding a very small quantity of copper sulphate to the water.

Diatoms form another distinct group of extremely interesting and important one-celled algae that are abundant in moist places everywhere. They are microscopic plants provided with silicious cell walls featuring attractive, characteristic markings in an almost endless variety of form and pattern. These cell walls are developed as two valves that fit together over the protoplast like the two halves

of a pillbox. The protoplast contains one, two, or more chloroplasts, but it is yellowish brown or straw colored owing to the mixture of carotin or xanthophyll with the chlorophyll. This mixture of pigments is often referred to as **diatomin.** Instead of starch, these plants store oil as a reserve food product. Some of the diatoms exhibit a

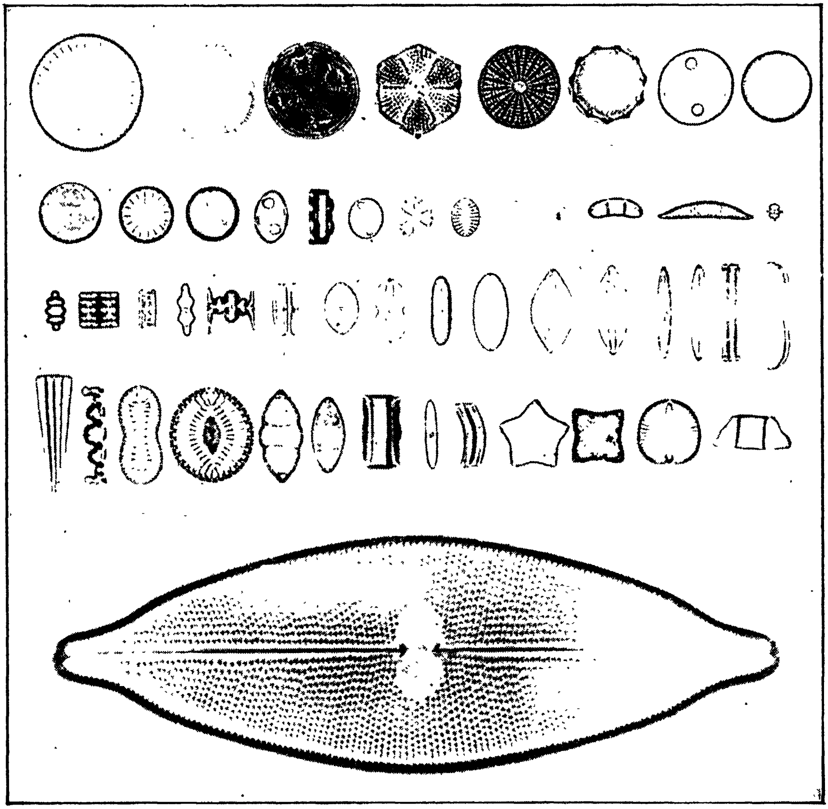


PLATE XXIII. Diatoms. *Photomicrographs by Phillip O. Gravelle.*

gliding movement that generally takes place in a series of jerks. This movement is effected by water currents caused by the flowing of protoplasm along the **raphe,** a very complicated cleft in the valve. In asexual reproduction, the protoplast divides and the daughter cells separate, each carrying a valve of the old cell wall and afterward building a new valve to complete the covering. These plants also reproduce sexually.

The importance of diatoms can hardly be overestimated. Either directly or indirectly they form a very large part of the food of

fishes and so have been called the "grasses of the sea." The almost indestructible shells of these organisms existing in enormous numbers during past geological ages form extensive deposits in different parts of the world.

In California, some of the deposits extend for miles and are several hundred feet deep. A single cubic centimeter of this material, known as diatomaceous earth, may contain between two and three million diatom shells. It is now believed that the oil produced in the cells of the diatoms through past ages is the chief source of the world's supply of petroleum. Diatomaceous earth forms the basis of metal polishes and is used as a bacteriological filter, as an abrasive, as an absorbent of nitroglycerine in the manufacture of dynamite, and as an insulator of heat in the construction of boilers and furnaces. Because of their delicate markings the shells of certain species are used to test microscope lenses. Some diatoms are responsible for objectionable odors and tastes in drinking water.

The Phaeophyceae (*phaios*—dusky; *phykos*) **or brown algae.** These are mostly marine algae and are most abundant and best developed in the cooler ocean waters of the temperate zone. They vary in size from small microscopic plants to plants that reach a length of 150 feet. In form they range from delicate filaments to tough, leathery, ribbonlike plants. Under normal conditions, all brown algae are attached by means of a **holdfast.** In addition to chlorophyll, the chloroplasts contain a brown pigment called **fucoxanthin** which is responsible for the color of the plants. Some species are merely an olive green, others are deep brown, depending upon the degree to which the chlorophyll is masked by the brown pigment.

Ectocarpus is a typical filamentous brown alga. The filaments branch and have the general appearance of those of the green algae; in fact, the brown algae are believed to be descendants of the green algae. *Ectocarpus* reproduces sexually and also by swimming spores. Here, as in all brown algae, both zoospores and gametes are characterized by a pair of laterally placed flagella.

Fucus may be considered a good example of the rockweeds that commonly grow between tide levels. It has a tough, leathery, repeatedly forking **thallus** buoyed up by internal **air sacs** developed at intervals in the flat branches. Only sexual reproduction occurs in *Fucus* (Fig. 281). In the swollen tips of the branches are **receptacles** in which the sex organs are found. In the surface of the receptables are little pits called **conceptacles,** within which the **antheridia** and **oögonia** are formed. Some species are monoecious, i.e., the antheridia and oögonia are borne on the same plant; others are dioecious, with antheridia and oögonia on separate plants. Each

oögonium gives rise to eight eggs which, after fertilization, may develop immediately into new leathery plants.

Sargassum or gulf weed, a relative of *Fucus,* grows abundantly in the tropical waters of the Caribbean. Detached pieces of these plants have drifted far out into the ocean where, propagating vegetatively, they have given rise to beds of floating seaweed thousands of square miles in extent. This great area off the

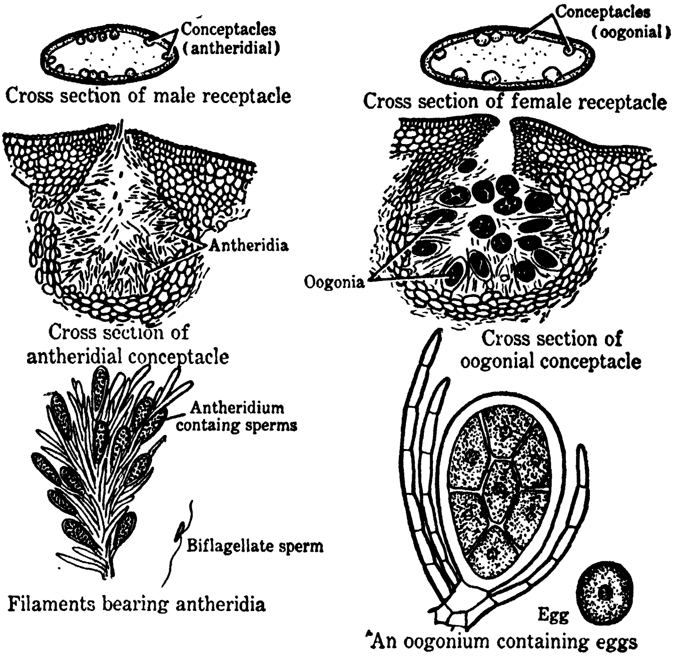


FIG. 281. Reproduction in *Fucus.* Drawing by Nelle Ammons.

southeastern coast of the United States is known as the Sargasso Sea. History tells us that, when Columbus sailed into this mass of floating seaweed, his sailors became greatly alarmed for they feared their ships would be grounded.

The kelps represent the third group of brown algae, and they are the largest of the thallophytes. Some kelps are only a few feet in length and plants 300 to 600 feet in length have been reported, but accurate measurements have established 150 feet as the maximum length attained. These leathery marine plants are attached by a **holdfast** and have a **stalk** bearing one or more leaflike **blades.** The tissues of these plants show a rather high degree of differentiation. *Nereocystis* has at the summit of the stalk a huge bladder which serves to buoy up the leaves floating near the surface. Sporangia are formed by these plants in large patches called **sori,** and in these

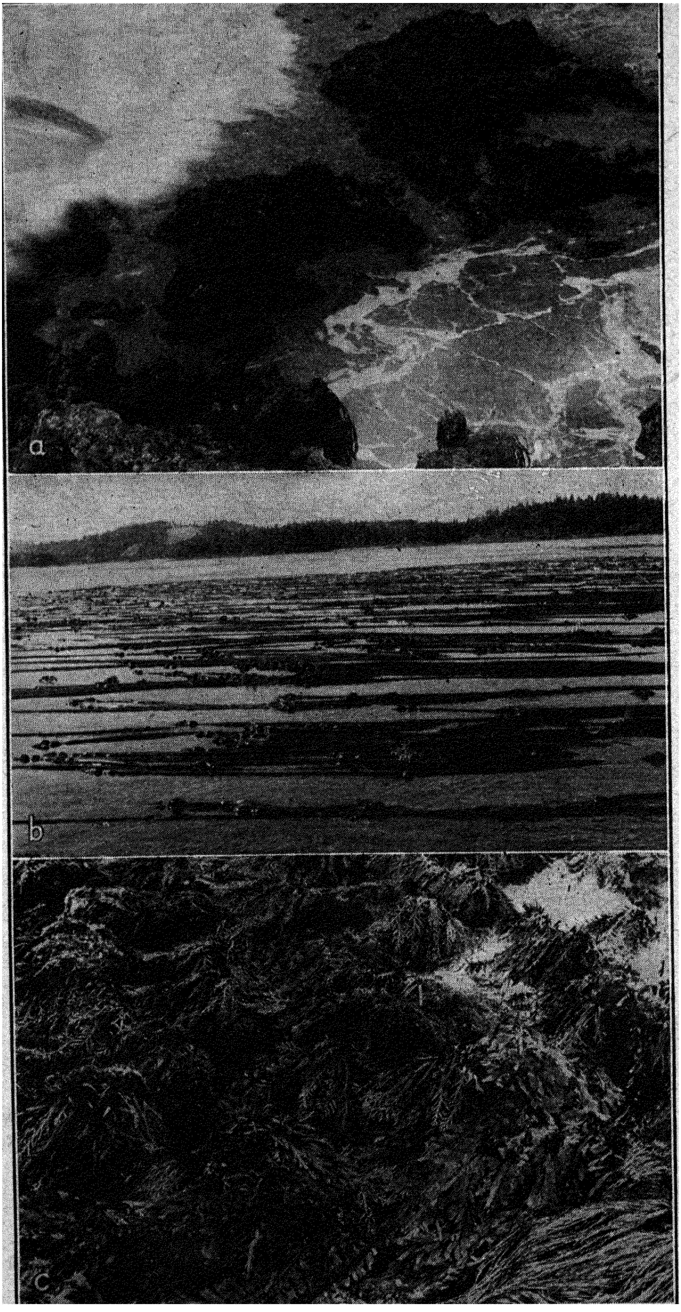


Plate XXIV. Kelps (*Phaeophyceae*). *a, Postelsia* in foreground, *Lessoniopsis* in the background; *b, Nereocystis; c, Halidrys. Photographs furnished by Robert H. Tschudy.*

sporangia the **zoospores** are developed. The zoospores give rise to very minute plants wholly unlike the kelp plant. The new plants are of two kinds, antheridial plants producing sperms, and oögonial

FIG. 282. "Sea palm," *Postelsia*. *Photograph furnished by Robert H. Tschudy.*

plants producing eggs. The small plants, then, are gametophytes. After fertilization the zygote with $2n$ chromosomes gives rise to a new kelp plant. Thus we observe in the life history of the kelps a large sporophyte with $2n$ chromosomes and a small gametophyte with n chromosomes. By means of spores, the sporophyte produces the gametophyte, and by the union of gametes, the gametophyte produces

the sporophyte. Later, we shall see that such an alternation of generations occurs in the life cycle of all higher plants. It will be remembered that alternation of sexual and asexual generations also occurs in certain animals.

In some parts of the world certain of the brown algae are used as food. In China and Japan they are cooked with fish. At one time

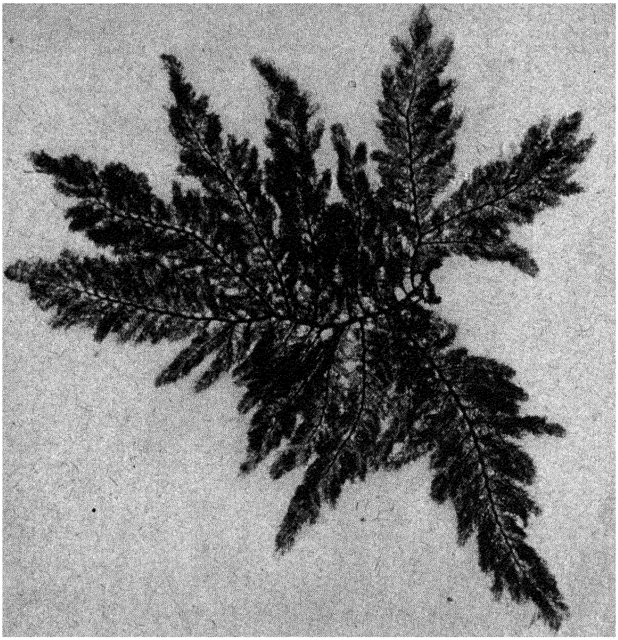


FIG. 283. A representative red alga. *Photograph furnished by the New York Botanical Garden.*

iodine was obtained principally from kelps. It is estimated that these plants contain a quantity of potassium salts sufficient to supply all the potassium used in fertilizers in the United States.

The Rhodophyceae (*rhodon*—rose; *phykos*) **or red algae.** These algae are chiefly marine plants that thrive best in the warmer waters of the temperate zone and in the tropical seas. Some grow in shallow water and others occur at surprisingly great depths, in fact, as far down as light can reach. Like the brown algae, although generally smaller and more filmy, these plants vary from extremely delicate, almost lacy, branching, filamentous forms to leathery, ribbonlike, or leaflike thallus plants (Fig. 283). In addition to the usual chloro-

plastid pigments a characteristic red pigment **(phycoerythrin)** is also present.

No zoospores or motile cells of any kind occur in the red algae. In the reproduction of the simpler forms, certain filaments produce a terminal **carpogonium** which functions as an oögonium in the production of a female gamete (Fig. 284). It bears a long protrusion called the **trichogyne** (thrix—*hair;* gyne—woman). Other branches bear terminal **antheridia,** and when these are mature the protoplast of each escapes into the water as a free-floating, non-motile cell

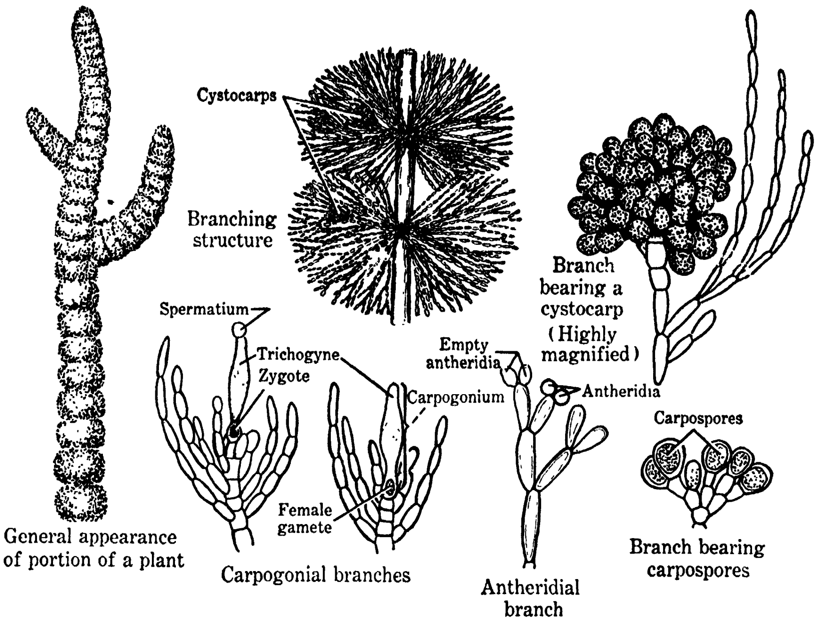


FIG. 284. *Batrachospermum,* a red alga. Drawing by Nelle P. Ammons.

called a **spermatium.** If one of the spermatia floats against a trichogyne, the nucleus of the spermatium divides and one of the resultant daughter nuclei moves on down and fuses with the nucleus of the female gamete at the base of the carpogonium. The zygote develops immediately, producing a number of filaments, the end cells of which become spores called **carpospores.** The carpospores are cut off and eventually give rise to new plants. The structures involved in the reproduction of all red algae are essentially the same, but the process becomes quite complicated in the higher forms. For example, in the life history of *Polysiphonia,* male and female plants (gametophytes) and spore-producing plants (sporophytes) occur in an alternation of generations such as we have seen in the life history of some of the brown algae.

Like all other algae, the Rhodophyceae contribute their share of fish food and are thus of indirect service to mankind. Moreover, in some parts of the world, particularly in Japan, certain species of red

algae are used as food and are considered real delicacies. Irish moss (*Chondrus crispus*) is cooked to make a kind of jelly dessert. **Dulse** (*Rhodymenia*) is eaten raw by some peoples. Agar-agar, used so much in medicine, bacteriological laboratories, and as food, is obtained from several species of red algae.

Fungi

In their general organization the plants of this group of thallophytes are similar to the algae. However, the fungi are unlike the algae in that they contain no chlorophyll and therefore are unable to manufacture their food. Practically all fungi must procure their food from other organic matter either living or dead. All organisms that feed on dead organic matter are called **saprophytes** (*sapios*—rotten; *phyton*), and those that feed upon living plants or animals are known as **parasites.**

This large group of plants presents a great range of variation in size, form, and habit. They are distributed throughout the world, and some of them may be found wherever life is possible. As parasites, they are responsible for a great number of animal and plant diseases. It is reported that in the tropics about 20 per cent of all human diseases are caused by fungi exclusive of bacteria. As saprophytes, they cause the deterioration of food supplies and the destruction of timber and other useful materials. However, fungi are not wholly detrimental, for, as we have already seen, their role in causing decay plays an important part in maintaining the carbon and nitrogen cycles, and other uses will be described in subsequent paragraphs.

In our study of the fungi we shall include five groups. Bacteria and slime molds are not usually classed with fungi, but since, with few exceptions, they are unable to manufacture their own food, they may be studied most conveniently here.

Schizomycetes (*schizo*—split; *mykes*—fungus) **or bacteria.** These fungi were first discovered by Leeuwenhoek in 1683. They are the smallest and simplest microscopic plants known. Bacteria are unicellular organisms, but their habit of secreting mucilage often causes them to form irregular masses or filaments called **colonies.** There is no well-defined nucleus and no chloroplast. Except for the absence of chlorophyll, bacteria are very similar to the blue-green algae. The cell is thought to have a rigid cell wall but this is not composed of cellulose.

Bacteria occur wherever life is possible. They are found in the soil at depths of 6 feet or more, and they ride the dust particles of the atmosphere at an elevation of several thousand feet. They have been found in hailstones, deep down in oil-wells, and in both fresh and salt water. Bacteria are extremely abundant in the upper layers of the soil, and the richer the soil the greater the bacterial population. A barren sandy soil may not contain more than 100,000 bacteria per gram of soil, whereas a fertile, cultivated loam may have 100,000,000 bacteria in each gram of soil. Bacteria are always with us—on our skin, in our mouths, and especially in the intestinal tract, where we have set up a sort of partnership with them that is mutually helpful.

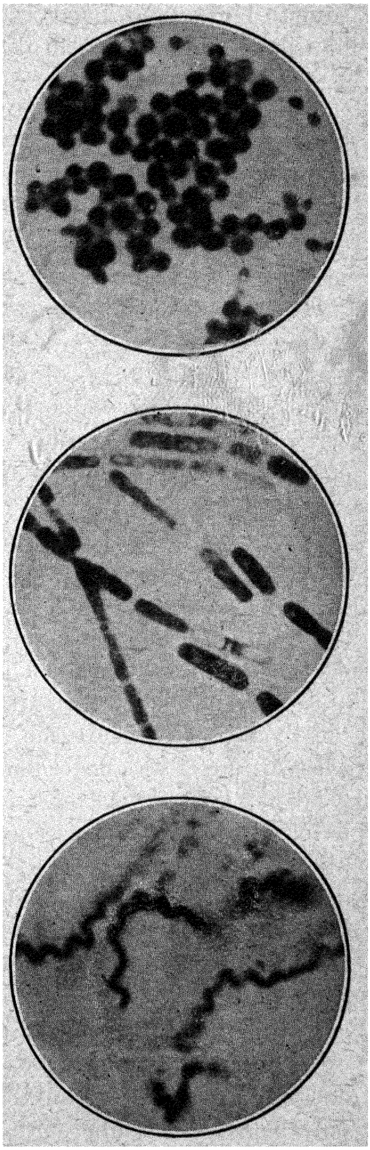


FIG. 285. Forms of bacteria. *Upper, coccus; middle, bacillus; lower, spirillum. Photomicrographs by permission of the General Biological Supply House.*

According to their general shape bacteria are arranged in three groups: the ball-shaped forms (**coccus** group), the rod-shaped bacteria (**bacillus** group), and the curved forms (**spirillum** group) (Fig. 285). Since they are so simple in structure, the different kinds of bacteria cannot be recognized and separated by noting only their external form. Bacteriologists have learned to distinguish one kind of bacteria from another by making use of staining reactions, by observing how they behave in cultures, and by noting the kind of colony they form. They seek to determine whether a given bacterium grows in the presence or absence of free oxygen, whether it produces gas when grown in a specific kind of nutrient material, and whether or not it liquefies gelatin. By the help of these physiological characteristics in addition to the morpho-

logical features, the student of bacteria is able to identify and classify them.

When examined under the microscope many of the bacteria are seen to be motile. Locomotion is made possible by means of long, hairlike flagella which in different forms appear on different parts of the cell. Motile forms are found mostly among the bacilli and the spirilla; with few exceptions the cocci are non-motile.

Reproduction takes place mainly by simple fission, and the cells divide very rapidly. Certain bacteria have been observed to enlarge to twice their size and divide within nine minutes. During the period of maximum growth rate of rapidly multiplying bacteria, the average generation time is about twenty minutes.

When conditions become unfavorable, bacteria may produce thick-walled "resting" spores which are extremely resistant to both high and low temperatures, drought, light, and chemical agents. These spores may remain viable for a long period. When favorable conditions are restored the spore capsule breaks and an active bacterium emerges. Generally but one spore is formed by a single bacterium, and since there is no multiplication of individuals, this cannot be considered a method of reproduction; it is merely a means of self-preservation.

Proper atmospheric conditions,. favorable moisture and temperature (70°–100° F.), and suitable food supply are essential for the growth and development of bacteria. Only a very few bacteria are able to manufacture their own food by means of energy obtained in the oxidation of inorganic iron, sulphur, or nitrogen compounds. These forms are called **chemosynthetic bacteria,** the simplest independent plants in existence. Like all other organisms, bacteria are living machines, and consequently they require a constant food supply. The bacteria produce the different enzymes necessary for the decomposition of the organic materials used, and extracellular digestion takes place. The production of enzymes accounts for the destructive nature of bacteria, for they enable bacteria to attack and disintegrate both living and dead organic bodies. Some forms of bacteria can utilize many kinds of food materials; others have a very restricted diet. Certain **pathogenic bacteria** produce diseases in man, his domestic animals, and plants. Usually they can be grown, if at all, only in a very specific culture medium.

FERMENTATION. Certain kinds of bacteria, in the absence of free oxygen, carry on the oxidation of carbohydrates anaerobically. This process, known as **fermentation,** is perhaps most familiar in the souring of milk. Lactic acid bacteria (*Streptococcus lactis*) living in the

milk produce the enzyme lactase, which acts upon the lactose or milk sugar, forming lactic acid. The presence of lactic acid is responsible for the sour taste of the milk. The making of sauerkraut likewise involves its formation. The shredded cabbage is placed in a dilute salt solution to prevent the action of the bacteria of decay. Certain lactic acid bacteria produce an enzyme that acts upon the sugar in the cabbage, converting it into lactic acid. Lactic acid formers are also responsible for the odor and taste of various kinds of cheese.

The metabolic processes of bacteria are responsible for the production of many other useful materials. Among them are acetone, methyl alcohol, ethyl alcohol, butyl alcohol, citric acid, acetic acid, and vitamin B_2. Bacteria are the helpful agents of man in many of his industrial activities. Their service is required in the retting of flax to remove the fibers from the stems, in the fermentation of ensilage, in the making of vinegar, in the preparation of dill pickles, in the curing of tobacco, and in the tanning of leather.

THE GROWTH AND CONTROL OF BACTERIA. If the nature and activity of a given bacterium is to be ascertained, it must be grown in **pure culture,** which is a collection of individuals belonging to a single species. Some proper nutrient material, such as gelatin or agar, called the **medium,** is provided. Precaution must be taken to have all bacterial life eliminated from the medium by **sterilization.**

There are several methods of sterilization, but heat is the agent commonly employed. Glassware may be sterilized by heating in an oven for an hour at a temperature of 170° C. Culture media and surgical dressings are usually sterilized in an **autoclave,** a metal container in which steam can be kept under pressure at a temperature higher than boiling. In the autoclave, media are sterilized for a period of 15 to 30 minutes at a pressure of 15 pounds, with a temperature of 120° C. The combined high temperature and moist heat readily kill all the spores that would ordinarily not be killed by boiling temperature alone. The autoclave is used in hospitals, dairy plants, disinfecting stations, and canneries. In the canning factory, the specially arranged autoclave is usually called a **process cooker.** The temperatures and pressures vary with the products being canned, but the principle remains the same, i.e., the use of steam under pressure resulting in a humid atmosphere with a high temperature. If spores are not present, boiling temperature will sterilize water, but the presence of resistant spores makes much higher temperatures necessary for dependable sterilization.

Heat is also used to control the bacterial content of milk. The method is called **pasteurization,** because the process originated in some of Pasteur's experiments. The most common practice involves a rapid heating of the milk to a temperature considerably below the boiling point (142°–145° F.) and then keeping it at this temperature for 30 minutes, after which it is cooled rapidly. Pasteurization de-

stroys the pathogenic bacteria that cause tuberculosis, typhoid, scarlet fever, diphtheria, undulant fever, and other disease-producing bacteria that may occur in milk. It is indeed very fortunate for us that only a few pathogenic bacteria are able to produce highly resistant spores. Today, health officers generally regard pasteurization of milk as a most important means of safeguarding public health.

PRESERVATION OF FOOD. That bacteria are the agents of food spoilage is now a matter of common knowledge, but long before this fact was known man had devised methods of preserving food. Drying was perhaps the earliest method; although it did not always kill the organisms, it did prevent reproduction and thus served to keep them in check. In addition to drying, man today employs methods of dehydration that make dehydrated foods possible--vegetables, eggs, milk, fruits, and other materials. Smoking of meats has long been a means of preserving them, but the action on the bacteria is not fully understood. Perhaps in some way the gaseous materials in the smoke are toxic to the organisms.

At an early date, people living in the colder regions utilized low temperatures as a means of preserving food. Bacteria cannot thrive when very low temperatures prevail; knowledge of this fact has given rise to the all-important business of refrigeration, which makes possible the enjoyment of tropical fruits and other foodstuffs in any quarter of the globe regardless of the distance involved in transportation.

Salt and sugar serve not only to make foods more palatable but also as effective preserving agents. If they are used in sufficient quantities, the greater osmotic concentration of the solution surrounding the bacteria results in an exosmosis of water causing complete plasmolysis and death of the cells.

In canning, heat is the agent that destroys the bacteria. Moist heat combined with pressure kills both spores and vegetative cells and therefore is most effective. Home-canned foods frequently deteriorate because the foodstuffs are subjected only to boiling temperature. Chemical preservatives are sometimes used, but they are largely prohibited or limited by pure food laws because they may be, and often are, injurious to health.

Bacteria not only are involved in the spoiling of food, but also they are sometimes responsible for food poisoning. Occasionally, we read newspaper reports of the serious illness or even death of the members of a family or of some other group of people sometime after they have dined together. Such illnesses are usually the result of "ptomaine" poisoning. When proteins are decomposed by bacteria, by-products called ptomaines are formed. We now

know that only a few of the ptomaines are toxic, but formerly, they were the substances that were thought to be responsible for food poisoning. It is now well established that food poisoning is caused by consuming food that has been previously tainted by toxins produced by some specific bacteria. Appearance of the food, odor, or taste may give no clue to the presence of such toxins.

A much rarer type of food poisoning is **botulism,** caused by toxins produced by the bacillus *Clostridium botulinum.* This spore-producing bacterium lives saprophytically in the soil and has been found on vegetables, fruits, and meats. The toxin produced is a powerful agent, and it is reported that death has resulted from the mere tasting of spoiled foods. Infected canned goods, such as olives, have been responsible for the majority of cases of botulism. An antitoxin has been developed, but it proves effective only when administered before the appearance of any of the symptoms.

BACTERIA AND DISEASE. A disease is some derangement in the structure or function, or both structure and function, of an organism. Some bacteria cause diseases, but fortunately most of them do not. To be a disease-producing agent, the bacterium must be able to penetrate the organism, to reproduce there, and to cause injury to the tissues. Undoubtedly this relationship between bacteria and other organisms is largely responsible for man's keen interest in bacteria. The foundations of modern bacteriology were laid in the latter part of the nineteenth century, a period which also marks the establishment of definite knowledge concerning the relation of bacteria to disease. Leaders among the workers of this period were Louis Pasteur and Robert Koch. Koch produced the first pure cultures of a pathogenic organism, discovered the tubercle bacillus, and formulated the rules for ascertaining beyond doubt that a specific organism is the cause of a given disease.

The scientific method of inquiry is well illustrated by the following set of rules known as Koch's postulates, which are to be used in determining whether a disease is the result of a certain specific organism:

1. The association of the suspected organism with the disease must be demonstrated in every case.

2. The supposedly causal organism must be isolated from the diseased tissues and grown in pure cultures.

3. Healthy plants or animals inoculated with organisms taken from the pure cultures must show the symptoms characteristic of the disease that is being investigated. Other healthy plants and animals kept under the same conditions as those to which the inoculated individuals are subjected are used as controls, and they should show no signs of any development of the disease.

4. The suspected organisms must be isolated from the inoculated individuals, grown in pure cultures, studied, and compared with the

organisms used in the inoculations until the investigator has demonstrated beyond doubt that the two organisms are of the identical species.

From a study of the above it will be seen that the scientist draws a sharp line between fact and mere opinion. He takes nothing for granted, and his conclusions are considered reliable only when fully

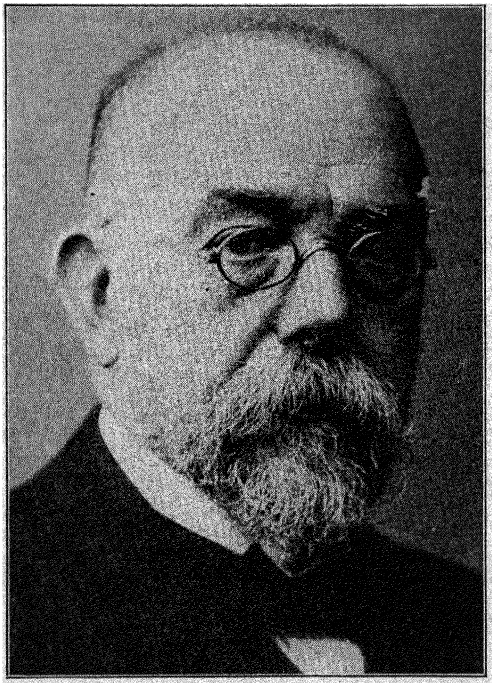


FIG. 286. Robert Koch (1843–1910). *Copyright by Acme Newspictures, New York. Reproduced by permission.*

adequate supporting evidence is provided by the most carefully controlled experiments.

In a previous chapter we saw how the body sets up certain natural defenses against disease. We have seen that agents produced in the body can destroy bacteria and the toxic substances produced in their metabolism. We have also learned that under certain conditions immunity to disease may be established. In addition to the diseases known to be caused by bacteria, there are a large number of infectious diseases whose cause is not known. Further investigation may yet reveal that some of them are bacterial diseases, or diseases caused by protozoans or some other well-known group of parasites. Within

comparatively recent years, some new disease-producing agents have been discovered whose existence was not previously known. Here belong the **Rickettsias** and the **viruses.**

Rickettsias. These organisms, named in honor of Ricketts, who died from typhus fever during his investigations of that disease, are very minute, rather indefinite, bacterialike bodies found in the intestines of the ticks which transmit Rocky Mountain spotted fever. It is now definitely established that these bodies are responsible for the disease. Other rickettsia diseases, such as typhus fever and trench fever, are also caused by rickettsia bodies transmitted by lice. All evidence points to the fact that these bodies are simple living organisms probably closely related to the bacteria.

Viruses are agents capable of producing certain diseases. Recent investigations have shown that some viruses, at least, such as the virus of tobacco mosaic, are complex molecules of high molecular weight. There has been much speculation concerning their nature. Some workers regard them as extremely minute living particles; others consider them non-living protein molecules that have certain properties characteristic of living cells.

Whatever the nature of the viruses, they are responsible for many diseases. In man, they cause smallpox, chickenpox, influenza, mumps, measles, herpes ("cold sore"), rabies, infantile paralysis, encephalitis ("sleeping sickness"), warts, and other diseases, probably including the common cold. In domesticated animals viruses cause fowl pox in chickens, equine encephalitis in horses, dog distemper, and other diseases. Leaf mosaic and curly top in various plants, yellow dwarfing of onions, leaf roll of potatoes, peach yellows, and other plant diseases are all known as virus diseases. In many instances the virus is spread from plant to plant by some insect vector.

In man and other animals, recovery from virus diseases leaves the organism with a high degree of immunity, and such immunity may be passively transferred by inoculations of serum. Protective vaccination using attenuated virus gives the greatest promise of preventing virus diseases. Such vaccination has practically eliminated smallpox, once a greatly dreaded epidemic in all civilized countries. It is now fairly well established that vaccination may prevent dog distemper and yellow fever. Rabies can be effectually prevented if vaccination is started immediately after the person is bitten by a mad dog.

Spirochetes. The spirochetes are on the borderline between bacteria and Protozoa. They lack nuclei and reproduce by transverse fission. In some respects they resemble the flagellates. The typical

spirochete is a rather long, relatively large organism with the body wound around a central axis or filament (Fig. 287). Most spirochetes have very flexible bodies, spirally twisted to resemble a corkscrew. They are a most important group from the standpoint of

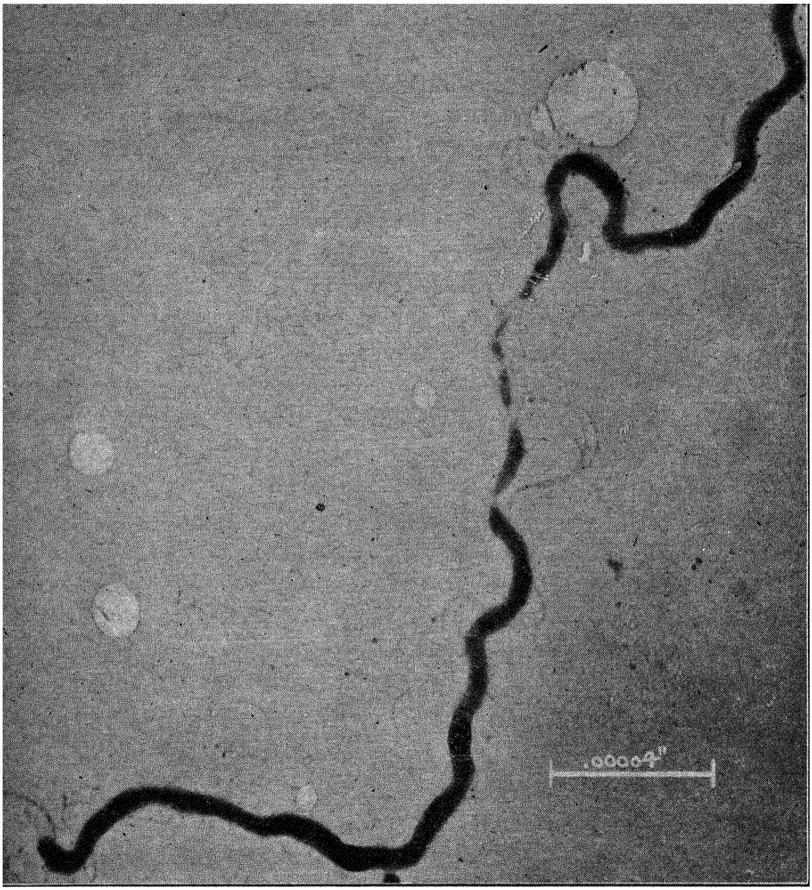


FIG. 287. A spirochete (*Treponema pallidum*) that causes syphilis. *Electron-micrograph, courtesy R.C.A. Victor Division, Radio Corporation of America.*

health. Among the human diseases caused by spirochetes are relapsing fever, syphilis, yaws, and infectious jaundice. Spirochetes are very often found in sores and ulcers along with various kinds of bacteria.

Relapsing fever is a disease the various forms of which are transmitted by ticks and lice. The disease is characterized by nausea, headache, back pains, and fever. These symptoms persist for a few

days and then disappear, only to recur again some four to eight days after the first crisis. Mortality from this disease is rather low.

Rat-bite fever is a result of infection, usually following the bite of a rat. In its early stages the disease resembles syphilis. There are cancerlike ulcers near the "bite"; the lymph glands become swollen; and the temperature rises. The attacks may come on at regular intervals and may persist for years.

Syphilis is a venereal disease which apparently had its origin in Haiti and was carried back to Europe by members of Columbus' crew. It has spread until today it is a world-wide scourge. The disease is transmitted in 90 per cent of the cases through sexual intercourse, although some cases of the infection being spread by other means have been known. The spirochetes of this disease usually affect the genito-urinary system. However, they are able to penetrate any mucous membrane or even a microscopic abrasion in the skin. From the region of infection they spread over the entire body. After the initial attack there may be a latent period of several weeks to months. During this period the organisms localize. Quite often this disease affects the nervous system, causing various types of paralysis and insanity. Other favorite places of localization are the aorta and the heart. The classic test for syphilis is the Wassermann reaction. *Today syphilis can be cured, but treatments for this terrible disease must be administered only by competent and reputable physicians.*

Yaws is a disease found in nearly all tropical countries. It resembles syphilis very markedly. The characteristic feature of the disease is the development of one or several crops of small, raspberry-like tumors on the skin. Yaws attacks the epidermis primarily. It may be transmitted by insects but it can also enter through any broken place in the skin. There is now considerable evidence that eye flies may be the vectors of the disease in certain sections of the world.

Bacteriophage. In bacterial cultures, there occurs a condition closely resembling virus diseases of higher plants and animals, known as **bacteriophagy.** The agent inducing this condition is called a **bacteriophage.** It has been shown that a bacteriophage is made up of extremely minute particles suspended in a liquid medium. When introduced into a bacterial culture, the bacteriophage causes the bacterial cells to swell and soon to dissolve in the medium (Fig. 288). Many kinds of bacteriophages have been discovered, each one being active on some different species of bacteria. We know as little or less

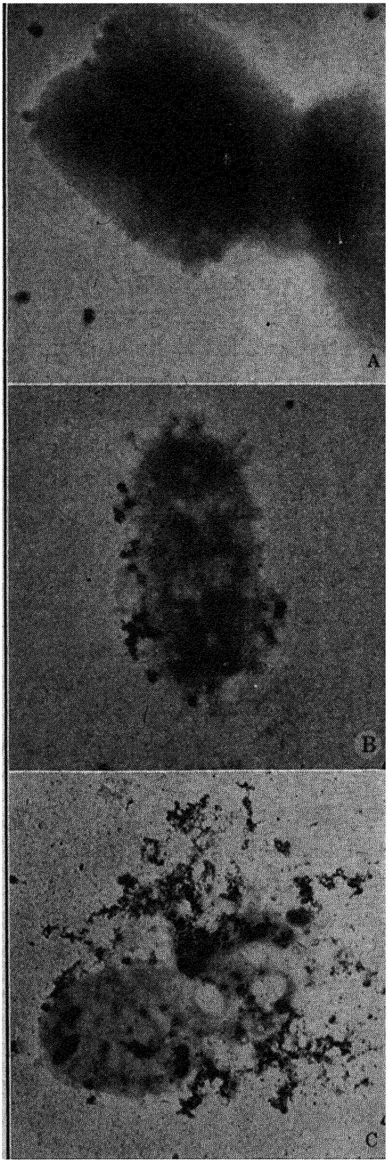


FIG. 288. Bacteriophage acting on bacteria, *E. coli,* magnified 12,000 ×. *A,* bacteriophage approaching bacteria. *B,* partial destruction after 20 min. *C,* complete destruction after 30 min. *Electron photographs courtesy R.C.A. Victor Division, Radio Corporation of America.*

about the nature of bacteriophage as about viruses, but its discoverer, d'Herelle, considered it an "ultramicroscopic, filtrable organism parasitic upon bacteria."

To realize how largely man is concerned with bacteria and the problems they create, it is only necessary to think of the comparatively recent development of antitoxins for the control of bacterial diseases; the construction of equipment for the sanitary disposal of sewage; the provisions made for the aeration and sterilization of drinking water; the dairy plants that provide for the pasteurization of milk; refrigeration plants; canning establishments; and the commercial development of antiseptics and sterilization apparatus of all kinds. We can readily understand that the problems of disease control, food preservation, and sanitation enlist the interest and labor of a large army of both skilled and unskilled workers and involve the expenditure of vast sums of money. The interest in sanitation, disease control, and antiseptic surgery, as now practiced, has all been developed since 1860.

In spite of the bad elements in bacterial society, there is also a decidedly helpful element absolutely necessary for our existence, in fact, for the existence of life itself. These indispensable bacteria are involved in the maintenance of the carbon and nitrogen cycles with which we are already

familiar. The ordinary man of the street gives little or no thought to this abundant bacterial life, and yet probably no group of plants is so fundamentally related to his general welfare and comfort, so necessary for his very existence.

Myxomycetes (*myxa*—slime; *mykes*—fungus) **or slime molds.** These organisms exhibit both plant and animal characteristics to such

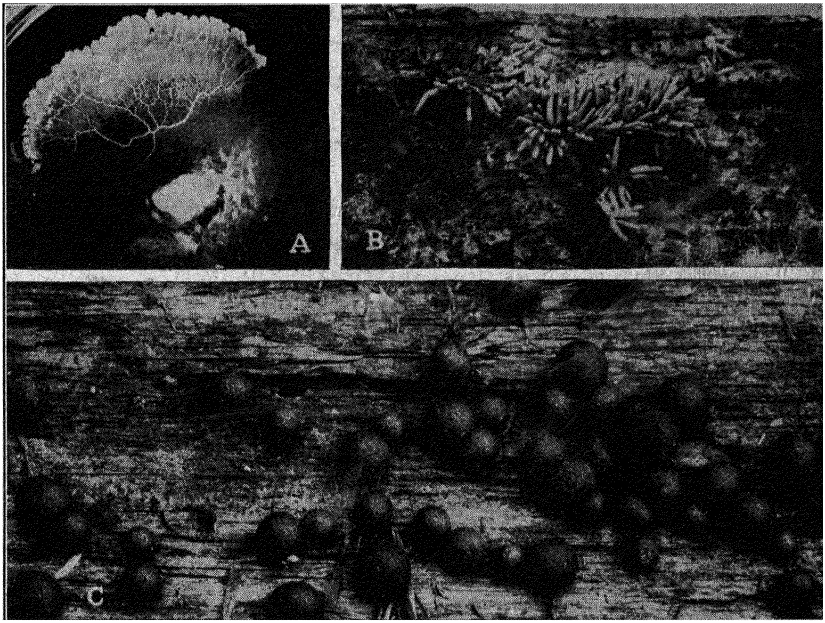


Fig. 289. Slime molds (Myxomycetes). *a,* plasmodium of a slime mold; *b* and *c,* sporangia of slime molds (*b, Arcyria; c, Lycogala*). *Photographs furnished by the New York Botanical Garden.*

a puzzling degree that both botanists and zoologists lay claim to them. They are mostly saprophytic. In the active vegetative state, they are multinucleate bodies of naked protoplasm that flow about and engulf their food in true ameboid fashion. Therefore they might be regarded as animals. However, in their reproductive activities and the formation of cellulose-coated spores, they resemble some of the fungi, and here we see their affinity with plants (Fig. 289).

The naked vegetative body of a slime mold is called a **plasmodium** (Fig. 289). It is very sensitive to light and grows only on moist surfaces in darkness or dense shade. In drier situations or when exposed to light, it begins its reproductive activity by forming a mass of spores or highly specialized **sporangia** containing spores. The spores, under favorable conditions, will germinate,

giving rise to ameboid protoplasts. The succeeding phases of the life history are subject to considerable variation but usually the "ameba" develops a flagellum, and in this stage rapid multiplication takes place by division. Finally the flagellated protoplasts lose their flagella and again become amebalike organisms which may now also multiply by fission. Ultimately these uninucleate "amebas" flow together and coalesce, forming the multinucleate plasmodium or slime mold.

Examined microscopically, the slime molds display a delicate structure and an array of brilliant colors that make the group singularly fascinating. Since most of the more than 250 recorded species grow on decaying logs, twigs, or leaves, they are of little economic importance. However, a few closely related parasitic forms are responsible for destructive plant diseases such as clubroot of cabbage.

Phycomycetes (*phykos*—alga; *mykes*). This and the two following groups comprise the true fungi. Many of the most common and destructive fungi, such as bread mold, water molds, "white rust" of mustards, and the downy mildews, are Phycomycetes. They are called algalike fungi because in structure and mode of reproduction they very closely resemble certain of the green algae. In fact some workers claim that the Phycomycetes are the descendants of some coenocytic green algae resembling *Vaucheria*.

Phycomycetes like the bacteria and all other fungi, have the ability to manufacture and secrete enzymes. The enzymes bring about the decomposition of various organic materials, and from the solutions of these materials the fungus obtains its nourishment. Thus digestion in all these plants is extracellular.

If we study some bread mold, we can obtain a picture not only of Phycomycetes but of fungi in general. The whitish, fluffy mass growing on a piece of bread is called the **mycelium.** It consists of a great number of branching, coenocytic filaments called **hyphae** (Fig. 290). The mycelium composed of hyphae represents the fundamental plan and working structure of this and all true fungi. Functionally, these hyphae are of three kinds: the **stolons** that grow along the surface and extend the mycelium over an increasingly larger area; the **rhizoids** (*rhiza*—root; *eidos*) that branch from the stolons and grow down into the food supply to absorb nutritive material for the mycelium; and the aerial hyphae, **sporangiophores,** so called because they branch from the stolons, grow erect, and bear terminal **sporangia.** Mature sporangia are globular black bodies that give rise to a large number of spores capable of germination and the production of new mycelia. We note here a very definite division of labor and a corresponding specialization of parts (Fig. 290).

Sexual reproduction also takes place when two contiguous hyphae develop connecting branches (Fig. 290). At the tip of each of these joining hyphae, a **gametangium** is cut off by a cross wall, and the multinucleate protoplast in each gametangium is called a **coenogamete.** At length the separating wall dissolves and the two coenogametes fuse, forming a zygote which develops a thick, rough, black wall about itself. After a period of rest, the zygote may germinate,

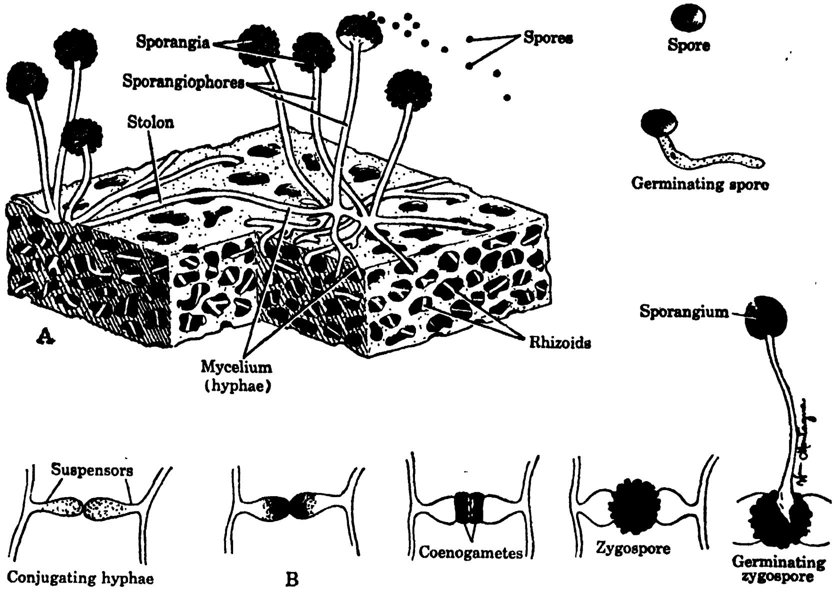


FIG. 290. Bread mold (*Rhizopus*). *A*, mycelium growing on bread and producing sporangia (asexual reproduction); *B*, sexual reproduction.

giving rise to an erect hypha which develops a terminal sporangium containing spores. It has been demonstrated that sexual reproduction can take place only when two different kinds of mycelia representing the so-called **plus** and **minus strains** are growing together in the same culture. Although we cannot observe the differences between the two strains, their behavior indicates clearly that a functional differentiation of sex is present. In the water molds, well-differentiated sex organs—antheridia and oögonia—are formed, which are very similar to those seen in the coenocytic green alga *Vaucheria.*

Bread mold is only one of the destructive Phycomycetes. Although most of the water molds are saprophytic, a few parasitic species that live on fish or fish eggs are serious pests in fish hatcheries and goldfish aquaria (Fig. 291). The downy mildews of grapes and cucum-

bers are ravaging diseases caused by parasitic Phycomycetes, but the most devastating marauder of the entire lot is *Phytophthora infestans,* the causative agent of potato blight (Fig. 292). In 1845, this fungus caused the total failure of the potato crop in Ireland and was directly or indirectly responsible for the death of 250,000 people, or $\frac{1}{32}$ of the entire population of Ireland. One species of Phycomycetes (*Empusa*) is parasitic on the housefly and destroys it by feeding on its tissues. If the work of *Empusa* were more universal and more

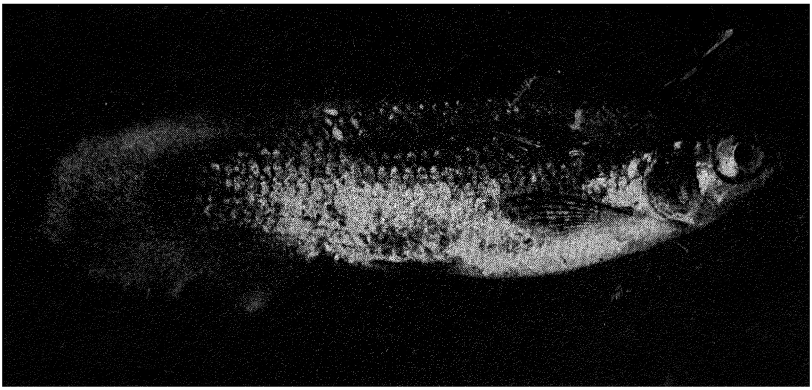


FIG. 291. *Saprolegnia* parasitic on goldfish. *Photograph furnished by the New York Botanical Garden.*

completely effective, its achievement would constitute one bright spot in an otherwise black record for the group.

Ascomycetes (*askos*—bladder; *mykes*). This is by far the largest group of fungi, and it includes a great variety of forms, many of which are responsible for serious diseases of cultivated plants. The hyphae of the mycelium differ from those of the Phycomycetes in being divided by cross walls into numerous short cells. The presence of septate hyphae in this and the next group clearly separates these groups from the Phycomycetes.

If we study *Peziza,* we can acquire some notion of the special features of the Ascomycetes. The mycelium of *Peziza* grows in decayed wood or in soils very rich in humus. Ordinarily, we do not see this hidden part of the plant, but it sooner or later develops a visible, cup-shaped body. In some species, the cup with its brilliant scarlet lining is very conspicuous. This is the fruiting body, composed of more or less closely compacted hyphae, and called the **ascocarp** (Fig. 293). The lining of the ascocarp, i.e., the **hymenium,** consists of a palisade-

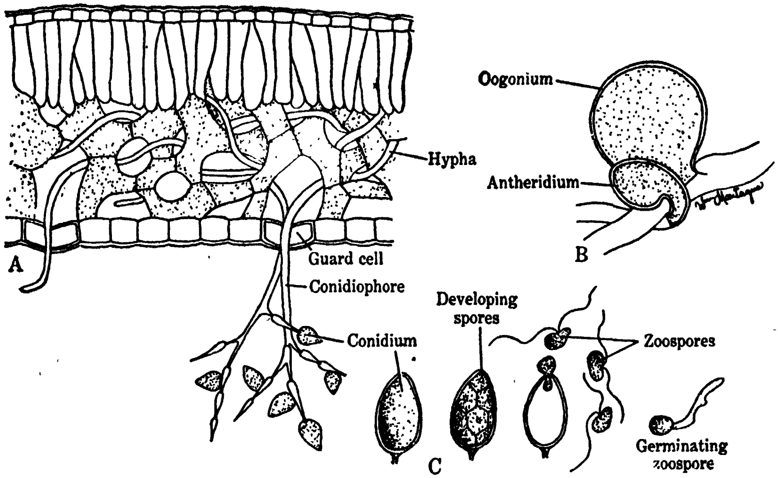


FIG. 292. The fungus that causes potato blight (*Phythophthora*). *A*. hyphae in a leaf of the host, and conidiophores growing out of the stomas. *B*, the sex organs; and *C*, stages in the germination of conidium and zoospore. *From various sources.*

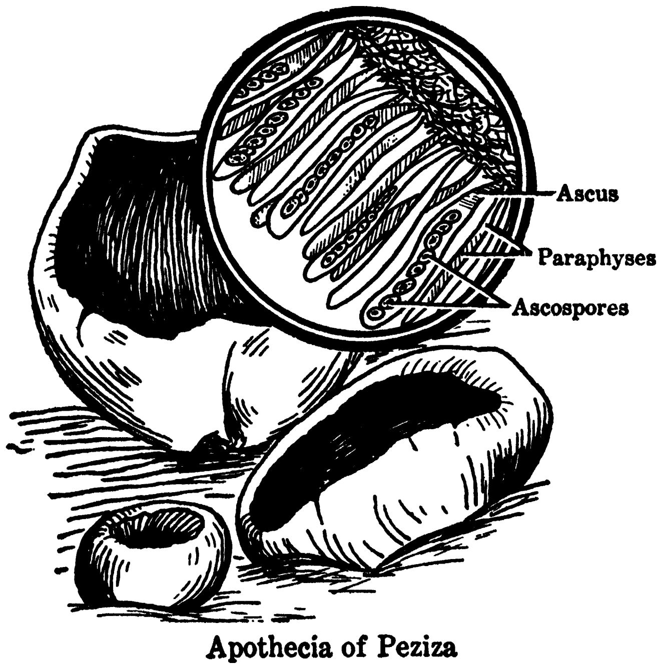


FIG. 293. The fruiting (spore-bearing) body of *Peziza*. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

like arrangement of sac-shaped, spore-bearing hyphae, the **asci,** and sterile hyphae called **paraphyses** (Fig. 293). **Ascospores** are produced in each ascus, which is the most essential distinguishing feature of the Ascomycetes. The ascus of *Peziza* contains eight ascospores, the usual number; but smaller or larger numbers occur in other Ascomycetes. The open, saucerlike or cup-shaped type of ascocarp such as that of *Peziza* is called an **apothecium.** In some forms, the ascocarp is flask shaped or spherical and opens by a tiny pore or is entirely closed. Such an ascocarp is called a **perithecium.**

The reproductive behavior of *Pyronema,* an ascomycete closely related to *Peziza,* has been carefully investigated. The mycelium produces both male and female **gametangia** lying near each other. The female gametangium—**ascogonium**—consists of two parts: a globular basal cell, from which extends an elongated tubular projection called the trichogyne, which closely resembles the trichogyne of red algae. Both male and female gametangia are multinucleate. The male gametangium is a terminal, cylindrical structure lying just beneath the ascogonium. The trichogyne bends round, making contact with the tip of the male gametangium, and, after the dissolution of the contiguous walls, its contents pass into the trichogyne and on into the basal cell where the two **coenogametes** fuse. The several nuclei pair but do not actually unite. The female gametangium now produces several hyphae into which pairs of nuclei pass. Cross walls are formed, dividing the hyphae into compartments. In the terminal compartment is a single pair of nuclei which fuse, giving rise to the $2n$ number of chromosomes. Then follow three successive divisions of this nucleus, giving rise to eight daughter nuclei which organize cytoplasm about themselves to form eight ascospores. One of the divisions is a reduction division restoring n chromosomes in the spores. Thus we see how the ascus with its spores arises as a result of sexual reproduction. Sterile hyphae arising beneath the female gametangium are associated with the asci in the formation of the hymenial layer, and other sterile hyphae are involved in the construction of the body of the ascocarp, upon which the hymenium rests.

Many Ascomycetes also produce spores called **conidia** which are cut off from the ends of short hyphae. Such conidia spread the fungus during the growing season and often occur in such numbers as to produce a white coating over the leaf. The coating may be seen on the leaves of lilac, clover, chestnut, willow, dandelion, and many other plants when infected with powdery mildew—an ascomycete that grows on the epidermis of leaves as an external parasite.

To the Ascomycetes belong the yeasts used in making bread and beer, and the fleshy morels and tuberous truffles so highly prized as food (Fig. 294). Truffles grow entirely under ground and are nosed out by specially trained pigs and dogs. Growing and collecting truffles has been an important business in France, where the exportation of these fungi may involve an annual exchange of several millions

of dollars. Ascomycetes include the ergot fungus that grows parasitically on rye and other grasses and may be responsible for serious

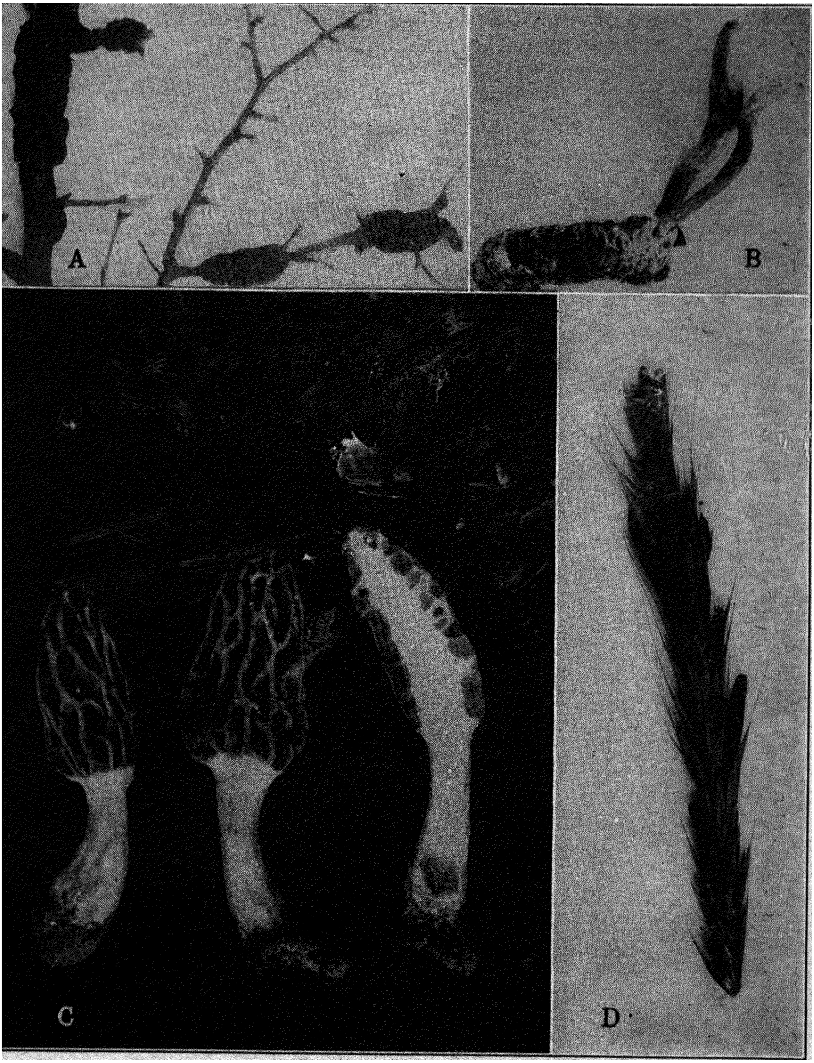


FIG. 294. Ascomycete fungi: *A,* black knot; *B, Cordyceps; C,* morel; *D,* ergot. *Photographs furnished by Bureau of Plant Industry (Stevenson).*

diseases in man and other animals; also the blue and green molds so commonly seen on jams, jellies, boots, and books. Certain of the blue molds are used in the manufacture of cheese, and the flavors of Roquefort, Gorgonzola, and Camembert are chiefly due to their influ-

ence. One genus (*Trichophyton*) of the Ascomycetes closely related to these molds contains parasitic fungi that cause ringworm and

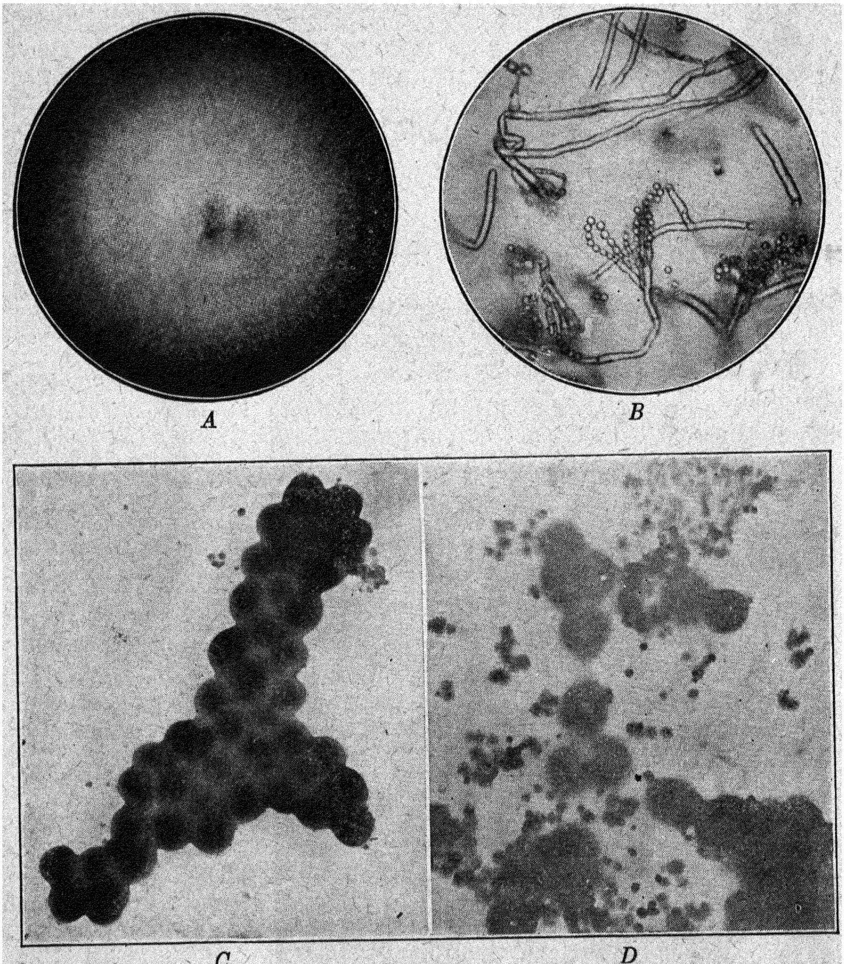


FIG. 295. *Penicillium.* *A*, an entire small colony of *Penicillium notatum*; *B*, hyphae and spores; *C*, electronmicrograph (40,000×) showing colony of bacteria (*Staphylococcus aureus*); *D*, same colony after disintegration by action of penicillin. *A and B photomicrographs furnished by the General Biological Supply House; C and D, courtesy R.C.A. Victor Division, Radio Corporation of America.*

athlete's foot. Many plant diseases are caused by the Ascomycetes. Black knot is a disease of plum and cherry trees characterized by the appearance on the twigs of black, warty, knotty excrescences which eventually kill the tree. The chestnut blight, introduced into the

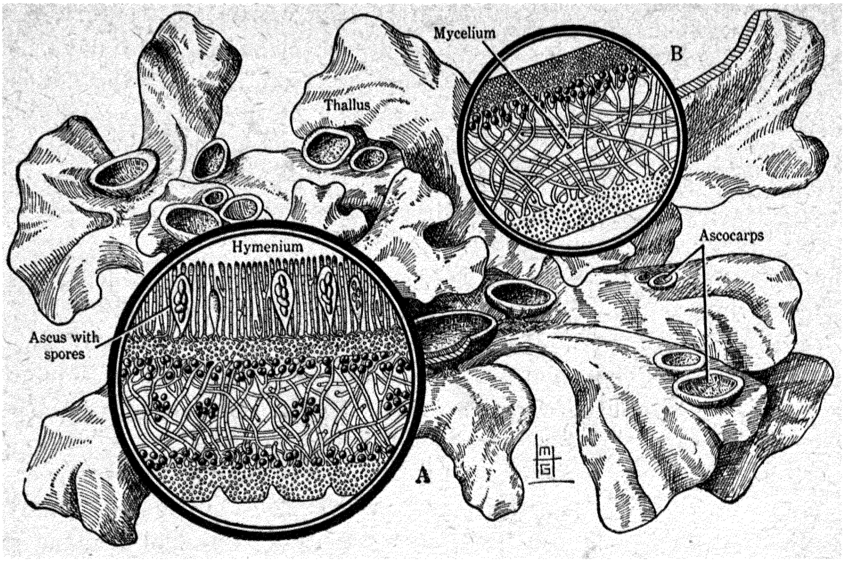
United States from Japan about 1904, in a quarter of a century has practically wiped out the native species of chestnut. And today, the lovely American elm seems doomed to the same fate by the Dutch elm disease unless effective measures can be devised to check the ravaging spread of the infectious fungus. Included among Ascomycetes are the numerous "Fungi imperfecti" responsible for many of the most devastating plant diseases, and so called because their life history is not fully known.

From the mold *Penicillium notatum* (Fig. 295) has been developed the germicide **penicillin,** which rivals the sulfa drugs in its action against disease germs. Penicillin was discovered by Alexander Fleming, an Englishman, and was first used to treat disease in man in 1941. Since its discovery it has come into widespread use, and new methods of extraction have radically reduced its cost.

Lichens. The irregular, grayish-green plants that are seen plastering rocks, old fences, or tree trunks are lichens. They are not simply fungi but dual plants, each of which consists of an algal component and a fungal component living together in an intimate relationship (Fig. 296). The alga manufactures the food and the fungus takes up water and minerals from the substratum, a relationship known as **symbiosis.** Lichens are included here because in all but two or three known instances the fungus involved belongs to the ascomycete group. The algae involved are either unicellular green algae or blue-green algae. The fungus forms the principal body of the plant and completely surrounds and envelops the algal bodies.

Lichens vary greatly in form and structure. Some have the appearance of fine powder sprinkled over the rocks; some look like pieces of old felt clinging to the rock walls; and still others form long, thready pendants hanging from the branches of trees. More than 4,000 forms have been described. Lichens are of three types: **crustose,** forming a crust on trees, rocks, and soil; **foliose,** growing as flat thalli; and erect or pendent **fruticose** lichens. They are all very resistant to drying and can thrive on bare rocks where no other plants can grow. For this reason lichens are pioneer plants on exposed rock surfaces and therefore soil formers of the very first importance. "Reindeer moss" is a lichen that furnishes food for the caribou when no other food is available.

The fungal component of a lichen produces ascocarps with asci and ascospores, and reproduction takes place as in other Ascomycetes (Fig. 296). More often lichens reproduce by means of **soredia,** small groups of algal cells enmeshed in a mass of hyphae. The soredia



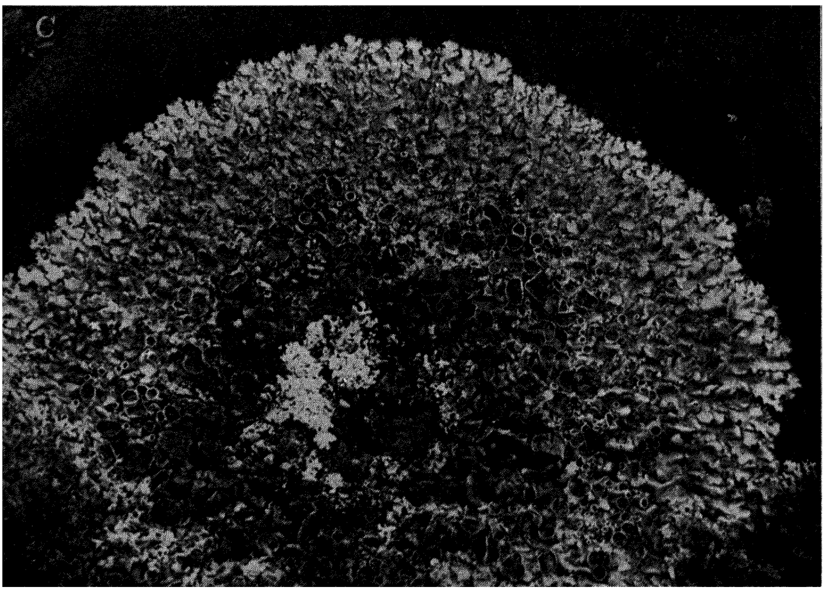


FIG. 296. Habit of lichen showing ascocarps. Inset *A*, section of ascocarp showing hyphae, algal cells, and hymenium with asci and paraphyses. Inset *B*, section of lichen thallus composed of hyphae investing algal cells. *C*, photograph of foliose lichen (*Parmelia*). *Photograph furnished by R. B. Wylie.*

become detached and when carried by the wind to some favorable place may give rise to a new lichen.

In addition to their great service as soil formers, lichens are sometimes used as food, both by man and beast. The Eskimos utilize some species as food, and the manna of Biblical record may have been a lichen of some kind. The litmus of chemical laboratories is produced by certain lichens, and lichens furnished purple and blue dyes for the Mediterranean peoples in the days of the ancient Greeks and Romans.

The Basidiomycetes (*basis*—pedestal; *mykes*). In number of species this group ranks second to the Ascomycetes. The distinctive character that gives name to the class is the **basidium,** a club-shaped hypha that bears **basidiospores.** One spore is borne at the end of a slender emergence (**sterigma**—a support), and each basidium usually bears four such **sterigmata.** The class is subdivided into three groups.

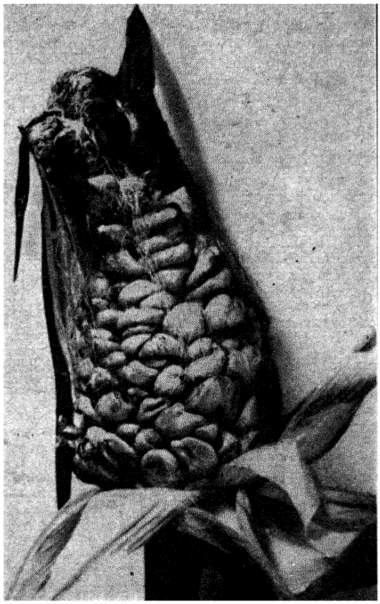


FIG. 297. Corn smut. *Photograph furnished by H. Lee Dean.*

The **Hemibasidiomycetes** or **smuts** are considered the most primitive of the Basidiomycetes. They infect corn, wheat, oats, and other cereals, causing tremendous annual losses in crop yields. The mycelium invades the tissues of the plant and can be detected only by microscopic examination. Finally, black, sooty masses of spores appear on the surface of the plant, especially in the flower clusters. They usually occupy the places where grains would normally appear (Fig. 297). Each spore is developed from a segment of a hypha, and the entire mycelium, or most of it, is converted into spores.

There are three types of host infection. **Seedling infection** occurs in bunt or stinking smut of wheat, covered smut of barley and all oat smuts, kernel smut of sorghums, and millet smuts. In these smuts the spores adhering to the surface of the seeds germinate when the seeds do. The hyphae of the smut at once grow into the tissues of the seedling and ramify throughout the developing plant. **Flower infection** occurs in loose smuts of wheat and barley. These

spores can infect only the ovary. When the young embryo forms, it already contains the beginning of a mycelium. When the seed germinates, this mycelium starts growth and extends itself throughout all the tissues of the developing host. In corn smut, **local infection** may occur in any part of the young plant, and the growth of the mycelium is confined to the localized areas. In the first of these types, seed treatment with such chemical reagents as copper sulphate, copper carbonate, or formaldehyde is an effective control measure. In the second type, hot-water treatment of the seed destroys the dormant mycelium but does not injure the embryo. In the third type, control measures are less definite and less successful, but a limited control can be had by collecting and burning the smut "boils" before spores have been discharged and by the proper rotation of crops.

In corn smut the spores have thick walls and remain alive in the soil throughout the winter. In the spring they germinate forming a short, four-celled hypha, the basidium, sometimes called a **promycelium.** Each cell of the basidium produces a sterigma bearing a basidiospore. When the basidiospores are blown about, they infect the new corn plants. Only localized regions of the plant are infected, and the part affected enlarges and produces a glistening, silvery, tumorlike growth which later becomes black and breaks up into an enormous number of the thick-walled spores. The spores are scattered by the wind to seed the soil, and the following season, when they germinate, a new crop of basidiospores is produced.

The **Protobasidiomycetes** or **rust fungi** are parasites on many widely different hosts found principally among the seed plants. Familiar examples are the stem rust of such cereals as wheat, oats, barley, and rye; apple rust; blister rust of pines; rust of raspberry and blackberry; and asparagus rust. The rusts are responsible for heavy annual losses in the yield of grains. In one year alone, black stem rust caused a loss of wheat in the United States and Canada of approximately 280,000,000 bushels.

The rusts are so called because the emergent spores form rust-colored patches on the surface of the host. In wheat rust, these reddish blotches appear on the stem and leaves in summer and enormous numbers of red spores **(uredospores)** are liberated, spreading the fungus far and wide. Thus new plants become infected with the mycelium of the rust fungus (Fig. 298). In late summer the same mycelium gives rise to masses of black spores **(teleutospores)** that live over until spring, when they germinate and form basidia (promycelia). Each promycelium forms four basidiospores which can germinate *only* on certain species of barberry. If a barberry leaf is infected, the hyphae grow through the tissues of the leaf, and at length branches emerge forming a mass on the lower surface called

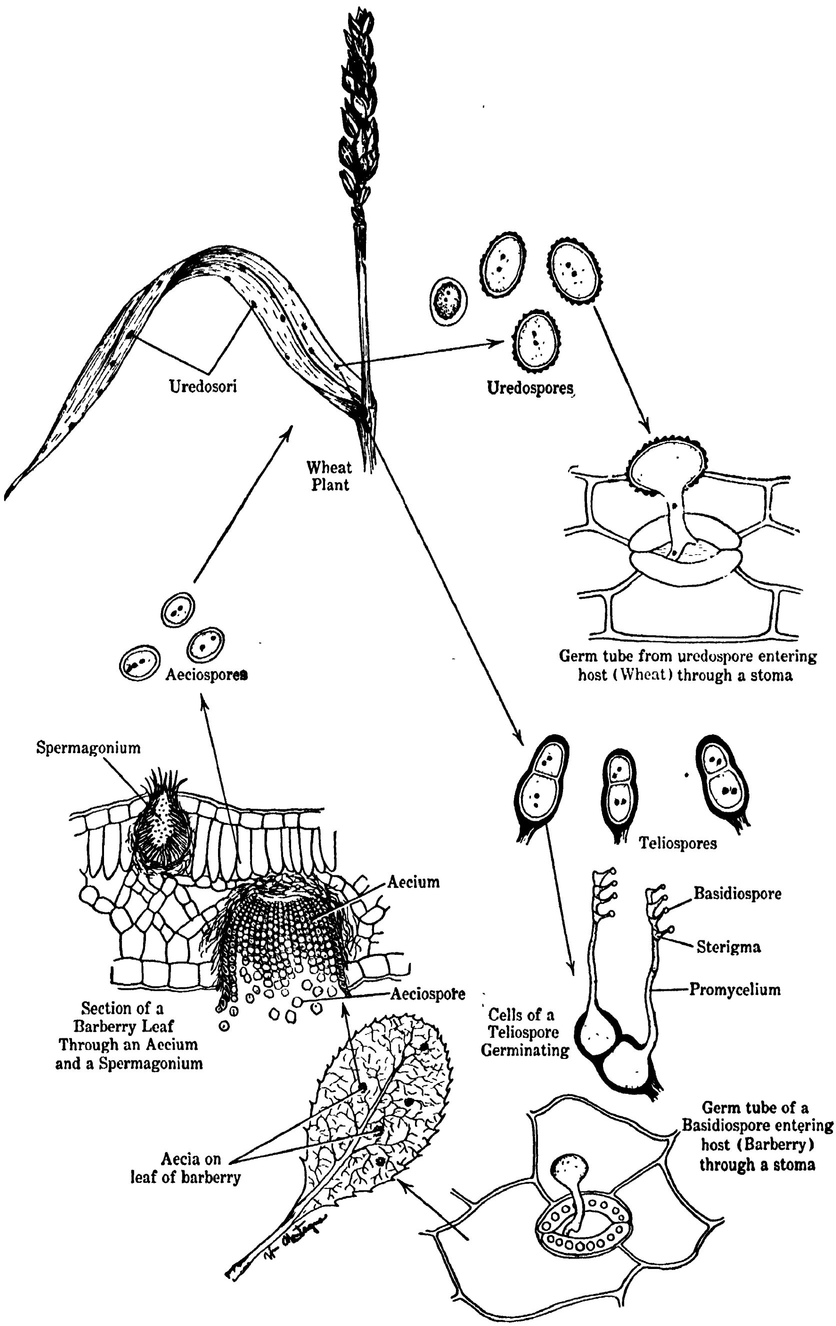


FIG. 298. Life cycle of wheat rust (*Puccinia graminis*).

a **cluster cup** or **aecium.** In this cuplike aecium, **aeciospores** are formed which can germinate *only* on new wheat plants of the season and thus continue the cycle. It is obvious that such rusts requiring two hosts on which to complete the life cycle can best be controlled by the elimination of one host or the other. Control is being attempted for wheat rust by eradicating the barberry. In apple rust, the red cedar is the alternate host to be eliminated, and the wild currants and gooseberries must be destroyed to protect the white pines against the ravages of the white pine blister rust. Some rusts have much shorter life cycles requiring but one host.

To the **Eubasidiomycetes** or true Basidiomycetes belong the toadstools, bracket fungi, puffballs, and stinkhorns. The group includes many wood-rotting fungi and the greater number of the edible mushrooms. We can form some conception of the essential features of these fungi by studying the common field mushroom (*Agraricus campestris*), the most highly prized market mushroom. The annual production of this mushroom amounts to 35,000,000 pounds with a market value of $7,000,000.

The common field mushroom is a saprophytic fungus whose mycelium thrives in a rich bed of humus. When a sufficient amount of food has been stored, a number of hyphae form a compact globular body called a **button.** The button enlarges, and the hyphae become differentiated to form specialized regions whose further development gives rise to the familiar toadstool (Fig. 299). Here we recognize the elongated axis known as the **stipe** supporting the shieldlike cap or **pileus** on the under surface of which are the **lamellae** or **gills** radiating from the stipe and extending to the margin of the pileus.

This toadstool is technically known as the **sporophore.** If a cross section of one of the gills is examined with the microscope, the surface is seen to be studded with very short, non-septate, club-shaped hyphae, the basidia, set very closely together in a continuous **hymenial layer.**

The capacity for spore production in each sporophore of this group is enormous. It has been estimated that a sporophore of the common field mushroom will produce 1,800,000,000 spores, and a big bracket fungus can produce in one year 100,000,000,000 spores. It has been calculated that a giant puffball produces 7,000,000,000,000 spores. It is very fortunate for us that most of these spores do not succeed in giving rise to new plants.

Some mushrooms are edible; others are deadly poisonous. It is frequently thought that the term toadstool refers to poisonous species and that the non-poisonous edible forms are mushrooms. As a matter

of fact, there is no distinction between toadstools and mushrooms, since a species that is edible at one stage of its development may be poisonous at some later stage. There is no foolproof method that will insure a clear-cut distinction between edible and poisonous mush-

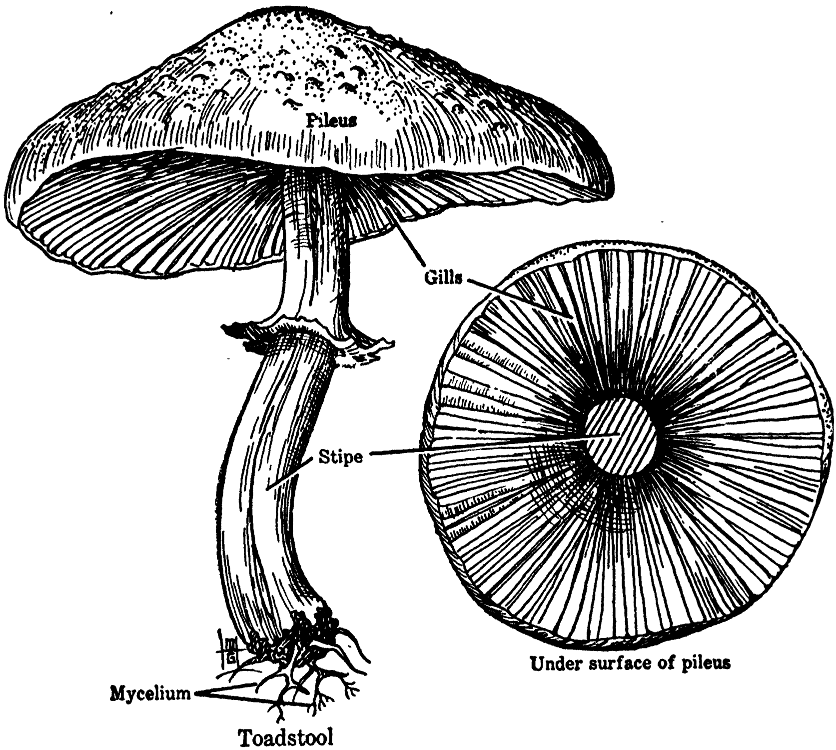


FIG. 299. A toadstool, a Eubasidiomycete.

rooms. The only rule that will guarantee assured safety is this: never eat mushrooms unless they are collected by someone who is thoroughly qualified to identify the different species and to decide which are edible and which are poisonous.

Many of the species collectively known as the wood-rotting fungi bring about the staining and rotting of wood. Prominent among them are the bracket fungi, frequently observed extending out horizontally from the trunk like so many shelves.

Whatever their form and wherever they may occur, the Basidiomycetes are quite generally believed to be the descendants of the Ascomycetes. They are the fungi best known to people everywhere, because of their conspicuous fruiting bodies, the sporophores, and the

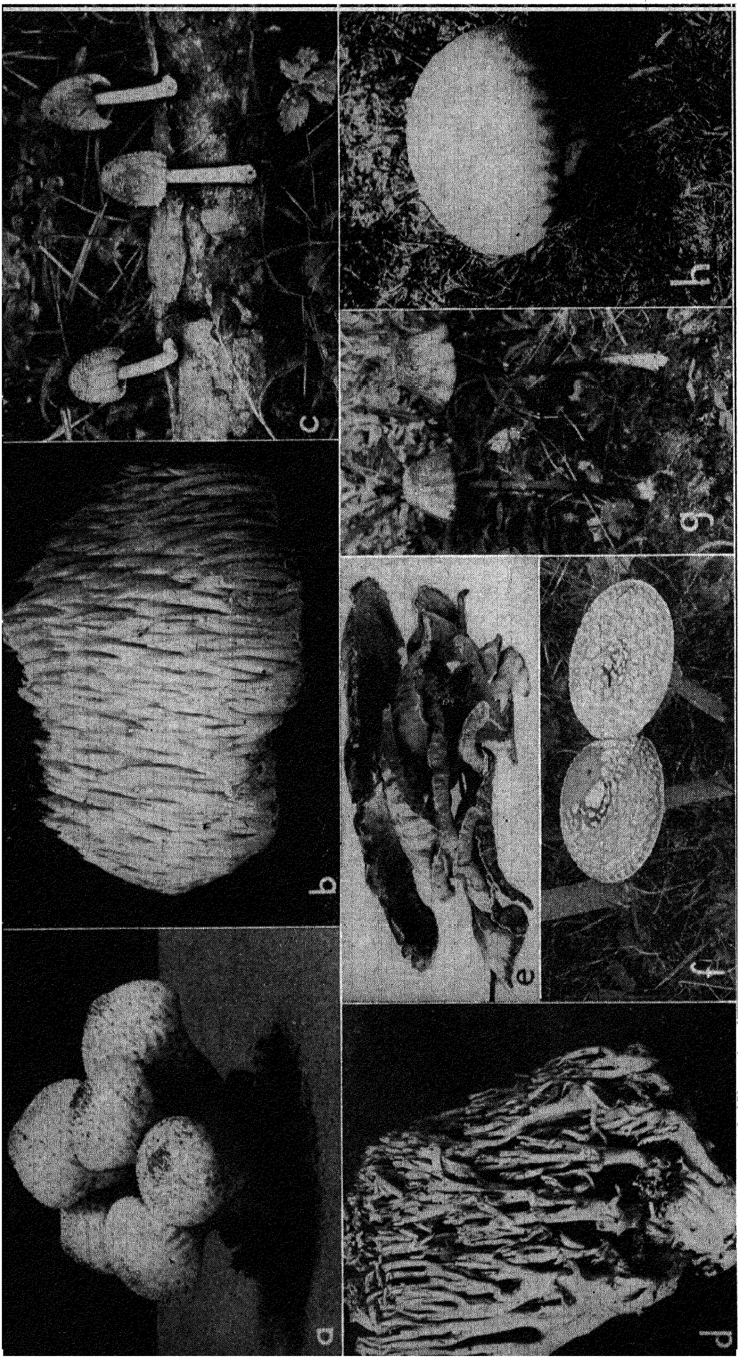


PLATE XXV. Basidiomycetes. *a*, *Lycoperdon*; *b*, *Hydnum*; *c*, *Coprinus*; *d*, *Clavaria*; *e*, *Polyporus*; *f*, *Amanita*; *g*, *Coprinus*; *h*, *Lycoperdon*. *Photographs a, b, d, e furnished by Bureau of Plant Industry (Stevenson), U. S. Department of Agriculture; c and g, by H. Lee Dean; f and h, by the General Biological Supply House.*

fact that so many of these are edible and have long been considered very select food material.

PHYLUM BRYOPHYTA

(*bryon*—moss; *phyton*)

We have seen that the algae are essentially aquatic plants, but the members of the second phylum of the plant kingdom are principally land plants. They are the **Bryophytes.** About 23,000 species are known in this phylum, arranged in two classes.

Hepaticae (*hepas*—liver). The liverworts are small inconspicuous plants growing usually in moist, well-shaded habitats, such as damp soil, rock cliffs, and tree trunks. Some species grow as floating plants. Some liverworts have a thallus body, and others, known as the leafy liverworts, possess lobed bodies, the lobes resembling the "leaves" of mosses.

One of the most common and familiar liverworts is *Marchantia,* which we shall study to obtain a picture of liverworts in general (Fig. 300). The conspicuous *Marchantia* plant is a green, repeatedly forking thallus anchored to the soil by hairlike outgrowths called **rhizoids.** The **thallus** is several cells in thickness and covered over by an epidermal layer. In the upper epidermis are the **air pores** that open into compartments or **air chambers.** Projecting upward from the floor of an air chamber are a number of short filaments made up of cells containing chloroplasts. In some respects this organization resembles that of the leaf, and it is clear that *Marchantia* growing in an aerial environment is well equipped for photosynthetic work.

On the upper surface of the thallus are small cuplike structures called **cupules** in which are borne tiny green bodies, the **gemmas** (Figs. 134 and 300). Each gemma is in reality an embryonic thallus which will escape from the cupule and may eventually give rise to a new plant. This method of vegetative propagation is found in a number of liverworts and also in some mosses.

An inspection of *Marchantia* plants soon reveals that there are two kinds of thalli. From some thalli erect branches arise bearing terminal scalloped disks containing the **antheridia** (Fig. 300). On the other kind of thallus are similar erect branches each bearing a number of rays arranged like the ribs of an umbrella. On the under side of the central disk between the rays are the **archegonia,** the female sex organs. The **archegonium** is a flask-shaped organ, the bulbous part of which is called the **venter.** The venter contains the **egg.** It is surrounded by the tissues of the archegonial disk. The slender elon-

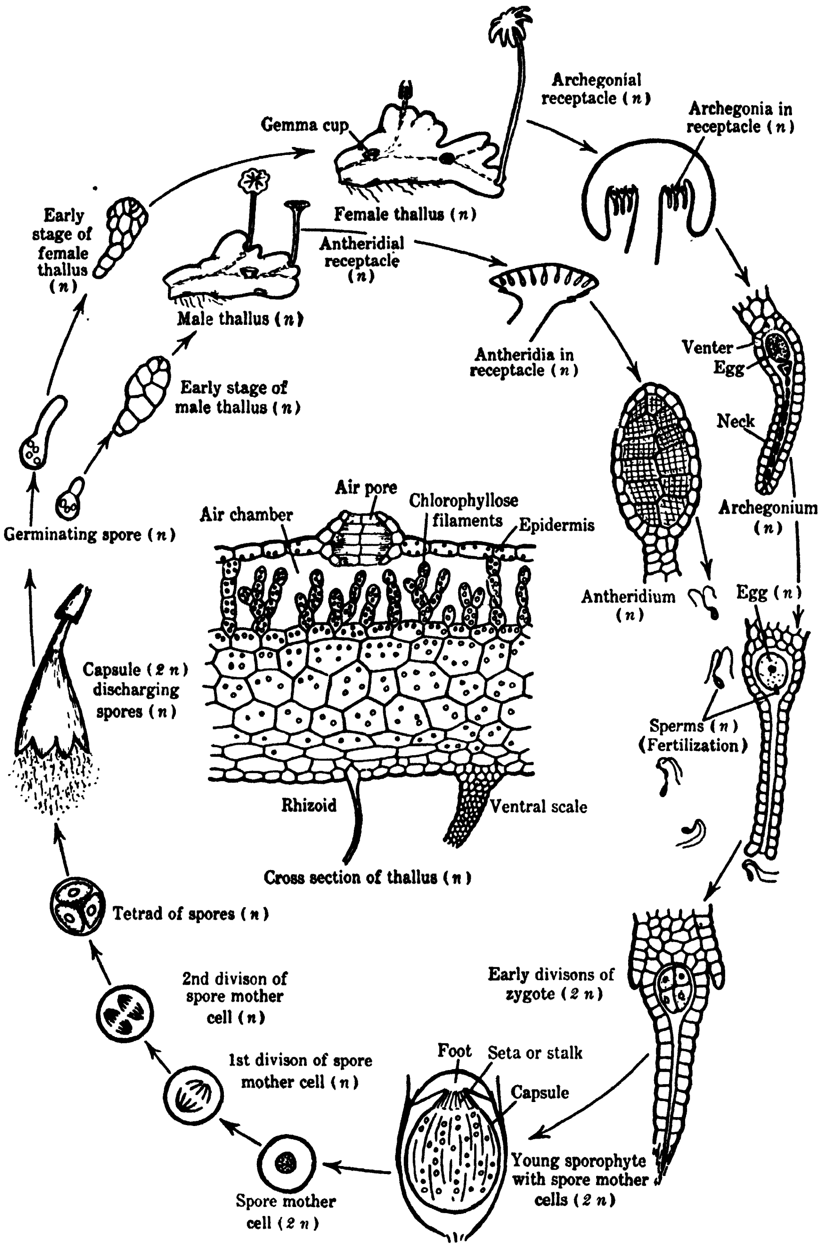


FIG. 300. Structure and life cycle of a liverwort, *Marchantia*. Note that the nuclei in the cells of all gametophytic structures have n chromosomes, and those of the cells of all sporophytic structures have $2n$ chromosomes. *Drawn by Nelle P. Ammons.*

gated part of the achegonium leading to the outside is the **neck.** The mature antheridia are stalked, ovoid organs, having a jacket of sterile cells that encloses the numerous biflagellate **sperms.** The antheridia are borne in chambers open to the outside through a pore in the upper surface of the disk. Thus we see that the conspicuous *Marchantia* plants are **gametophytes** bearing sex organs. The gametophytes are **dioecious,** i.e., the antheridia are borne on one thallus (male gametophyte) and the archegonia are borne on another thallus (female gametophyte).

At the time the sperms are discharged from the mature antheridia the archegonial branches of the female thallus are still very short and consequently the archegonia are but little elevated above the thallus (Fig. 300). If the thallus is covered with a film of water, sperms from the male plant falling into the water can swim to the archegonia, and through the necks to the eggs, where fertilization may take place. Several sperms may enter an archegonium, but only one fuses with the egg. After fertilization, the archegonial branch continues to elongate.

The zygote does not undergo meiosis as in the thallophytes but divides mitotically, giving rise to a plant body containing a large number of cells which become differentiated and specialized. As a result of this differentiation, three distinct regions are formed: the enlarged basal part **(foot)** imbedded in the gametophyte tissue of the lower side of the archegonial disk; a short stalk, the **seta,** connecting the foot with the terminal globular **capsule.** The capsule consists of a sterile wall enclosing a large number of spores and a considerable number of elongated, sterile cells called **elaters.** The elaters have walls with spiral thickenings and are quite hygroscopic so that when the capsule bursts they bend and twist in response to the slightest moisture changes, thus aiding in the dissemination of the spores. If the spores encounter favorable conditions, they will produce new *Marchantia* gametophytes, some male thalli and others female thalli. So we see that the zygote gives rise to a new plant body which, in turn, produces spores and is therefore a **sporophyte.** The sporophyte contains no chlorophyll and is parasitic on the gametophyte. Its cells contain $2n$ chromosomes, but, in the formation of spores, meiosis of the spore mother cells gives rise to spores with n chromosomes. Since this is the number of chromosomes characteristic of the gametophyte, it is obvious that the spore is the first cell of the new gametophyte generation. Here we have an alternation of generations, including a well-defined sporophyte body which, in later groups, enlarges and develops until it becomes completely

independent. In some liverworts, the sporophyte is nothing more than a spore-bearing capsule; but in the more highly specialized forms it becomes a green plant still dependent on the gametophyte but pointing the way to its ultimate emancipation.

The liverworts have been called the "amphibians" of the plant kingdom. Although they have acquired a land habit, they require a moist situation for the full completion of their life cycle. The establishment of the land habit brought about several important responses. The greatest danger encountered in the new habitat was desiccation, in response to which an epidermis was developed that greatly lessened the possibility of excess loss of water. Both sex organs develop protective jackets of sterile cells, and the archegonium appears as a new type of female sex organ. Alternation of generations becomes the established mode of reproductive activity, and the sporophyte generation is represented by a new type of plant body which produces light, aerial spores. Despite these advances, the aerial environment created a real problem for these pioneer land plants. The gametophytes had to manufacture all the food and produce the gametes, whereas the sporophyte, supported and fed by the gametophyte, had only to produce the spores. Now the new aerial environment, as compared to the old water habitat, is much more favorable for food manufacture and spore dispersal but more unfavorable for fertilization by swimming sperms. So the two functions of the gametophyte were incompatible in the new environment, and further progress necessitated a solution of the problem. It is apparent that the development of an independent, food-manufacturing sporophyte would be one way out of the difficulty, and we shall see later that this is precisely the course of development that took place in the evolution of the plant kingdom.

Musci (*muscus*—moss). The mosses include a much larger number of species than the liverworts and have a more conspicuous and important place in our flora. Usually, mosses are the only bryophytes observed by the average individual. Too frequently, algae and lichens are mistaken for mosses, so that one often hears the word "moss" applied to almost any collection of tiny green plants. The "long moss" or "Spanish moss" observed hanging from the branches of trees in many of the southern states is not a moss at all but a flowering plant closely related to the pineapple. Mosses are less restricted to moist habitats, and many species can grow in much drier places than those in which liverworts are usually found. In general they have a more erect habit than liverworts, and vigorous forms may attain a height of six or seven inches. The leafy shoot

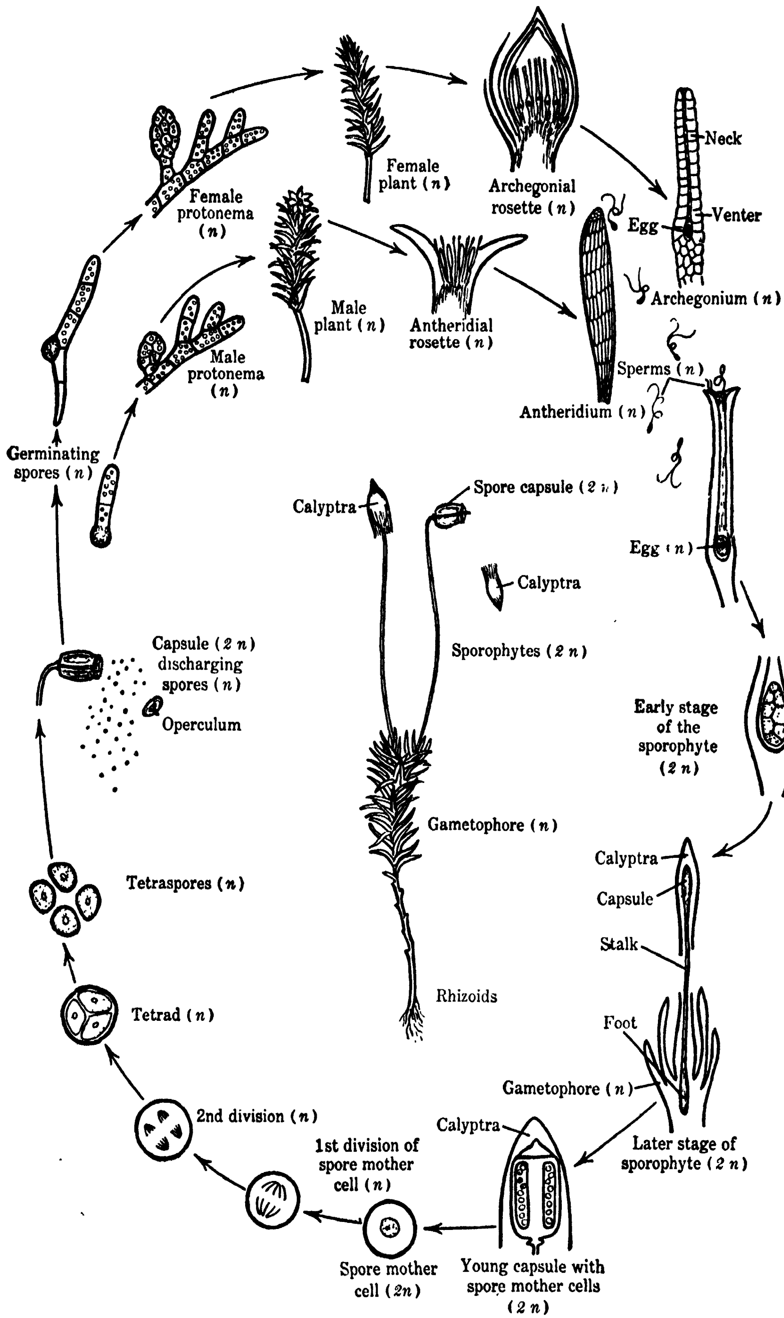


FIG. 301. Life cycle of a moss. *Drawn by Nelle P. Ammons.*

is the characteristic structure of all mosses, but the so-called leaves are not leaves such as those borne by the seed plants. Most mosses possess great power of vegetative reproduction so that moss plants usually occur in patches, cushions, or extensive mats.

Although mosses vary considerably in form, structure, and habit, there is enough similarity that a single life history will suffice to give a general concept of the organization and behavior of a moss plant. If we examine any well-known moss like the common hair-cap moss (*Polytrichum*) we shall see an erect leafy shoot in which the leaves are spirally arranged on a central **axis** (Fig. 301). The plant is anchored to the soil by absorptive **rhizoids.** The terminal leaves are arranged in a sort of rosette, and in the end of the axis surrounded by the leaves of the rosette are the sex organs. In *Polytrichum*, **antheridia** and **archegonia** occur on separate plants, but in some mosses both may be found on the same axis. Since it produces the sex organs, this moss plant is a gametophytic structure and it is generally called the **gametophore** (Fig. 301).

When the egg within the archegonium is fertilized, the resultant zygote develops into the sporophyte, which has an absorptive **foot,** a long stalk or **seta,** and a highly specialized spore-bearing **capsule** (Fig. 301). The foot remains firmly anchored in the axis of the gametophore, whence it obtains the food supply for the sporophyte. The capsule is surmounted by the remains of the old archegonium, a loose covering called the **calyptra,** which has beneath it a lid called the **operculum** (little lid). The removal of the operculum reveals a series of hygroscopic teeth, the **peristome,** folded neatly over the opening of the capsule and extending from its margin to the center. The teeth are extremely sensitive to moisture changes. When wet, they bend inward; when dry, they straighten out—movements that aid in the dissemination of the spores. The sporophyte usually contains chlorophyll, and in many instances both stalk and capsule are for a time entirely green.

The tissue within the young developing capsule gives rise to the spore mother cells. These cells undergo meiosis, and thus each spore mother cell produces four spores. The nucleus of the spore contains n chromosomes, the reduced number. It will be observed that sexual reproduction in mosses is very similar to that in the liverworts. If a spore encounters favorable conditions it germinates, giving rise to a branching, green, septate filament called the **protonema** (*protos*—first; *nemos*—thread) (Fig. 301). Sooner or later buds arise from this filament and develop into the erect leafy gametophores. Thus the spore, the first cell of the gametophytic generation, produces the

protonema which gives rise to erect leafy branches, the gametophores, and therefore both **protonema and gametophore make up the gametophyte.**

The bryophytes are of great scientific interest but have practically no economic importance. Peat moss or *Sphagnum* is involved in the formation of peat, which is utilized as a fertilizer, fuel, and packing material. *Sphagnum* is a great absorbent, and consequently certain species are used as surgical dressing. All mosses are water retainers and soil builders, but they have practically no other significant role except in the beautification of the landscape.

CHAPTER XVI

THE PLANT KINGDOM (*Continued*). WHAT ARE PTERIDOPHYTES AND SPERMATOPHYTES?

PHYLUM PTERIDOPHYTA

(*pteris*—fern; *phyton*)

The **pteridophytes** are better known to the average individual than the groups we have already studied. The group is extremely old, the earliest representatives having flourished many millions of years ago. Today, something more than 9,800 species of pteridophytes are known, but it is thought that at the peak of their development in the ancient period there were many more species than there are at present. Evidence indicates that some of the pteridophytes of the Coal Age were large trees, whereas those of today, for the most part, are relatively small plants. It is thought by many botanists that the group has been derived through primitive simple forms from a bryophyte ancestry. The modern representatives are divided into three groups.

Filicineae (*filix*—fern). The fern with its large, featherlike leaves is a familiar plant. The usually pinnate leaves are called **fronds,** and, when they are developing, they look as if they were coiled at the tip. The coiled appearance has suggested the term "fiddle heads," but the botanists call it **circinate vernation** (Fig. 302). It is a distinguishing characteristic of all ferns. The leaves arise from a well-developed stem that is anchored in the soil by numerous fibrous roots. In our ferns, the stem is an underground rhizome, but in tropical tree ferns the stems are erect and may reach a height of fifty feet, with leaves thirty feet long.

On the under side of the leaf, numerous, scattered, brown spots make their appearance, and a careful examination with a hand lens reveals clusters of small **sporangia.** These clusters are called **sori** (Fig. 303). When young, each sorus may be covered by a delicate membrane called the **indusium.** Within the sporangium the spore mother cells undergo meiosis so that each spore contains *n* chromosomes. Thus we see that this large, conspicuous, highly developed

fern plant is the sporophyte which gives rise to spores—the first cells of the gametophytic generation.

The sporangium is so constructed that when fully matured it opens and catapults the spores into the air (Fig. 303). If the spores fall

FIG. 302. Fiddle heads (crosiers) of the fern *Osmunda*. *Photograph furnished by the Brooklyn Botanical Garden (Sydney Lasken).*

on favorable soil, they may germinate and give rise, not to fern sporophytes, but to small, green, thallus plants that are attached to the soil by means of rhizoids. Such a thallus is called a **prothallium** (Fig. 303). On its undersurface, near the basal end, the small, globular **antheridia** appear among the rhizoids, and nearer the apical end are the **archegonia**. Thus we see that the prothallium is the fern gametophyte. The multiflagellate, coiled sperms produced in

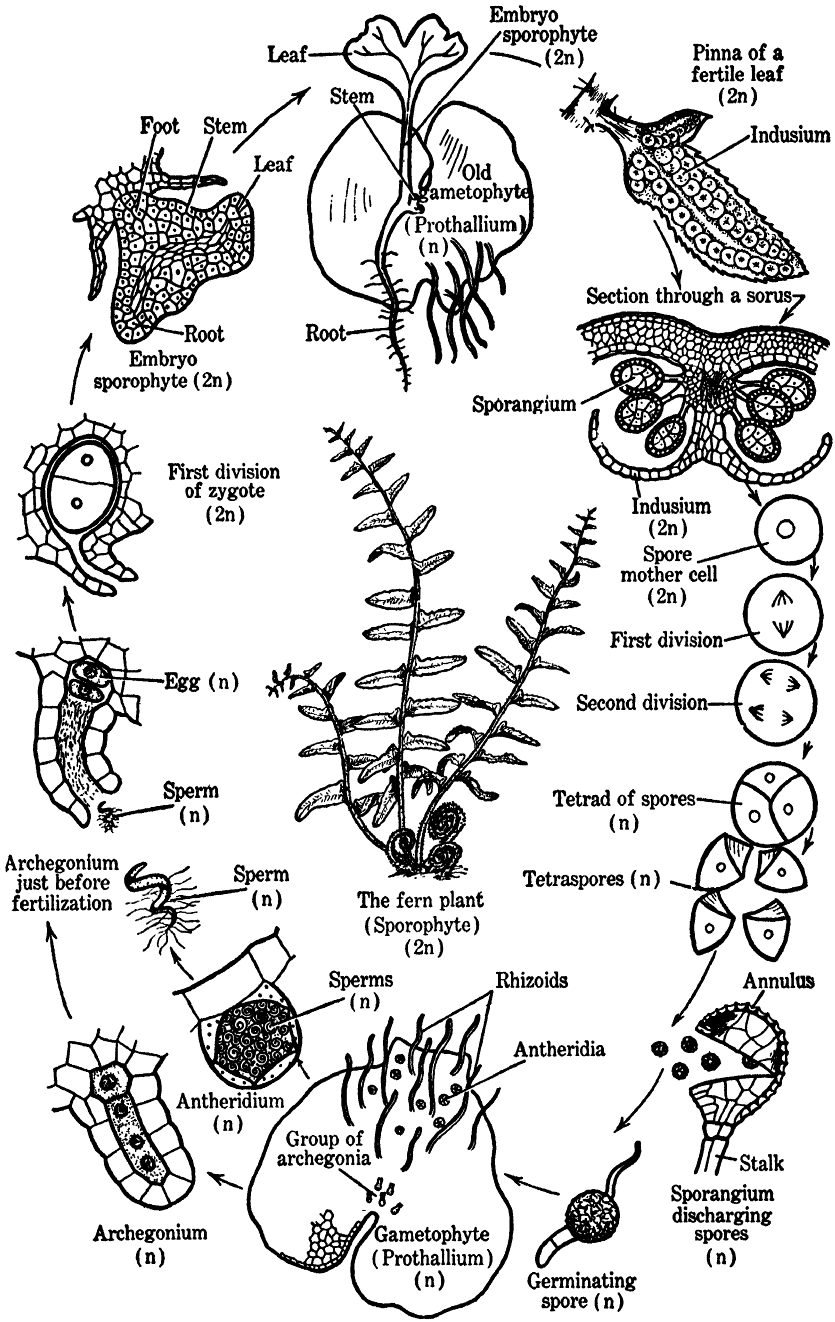


Fig. 303. Life cycle of a fern.

the antheridia escape and swim into the archegonium, where one of them fertilizes the egg.

The zygote soon begins to divide and grows into an **embryo** with a horizontal **foot** imbedded in the gametophyte. Through the medium of this foot the embryo gets its first food from the gametophyte and grows into the new sporophyte (Fig. 303). From the very beginning of its first, small **leaf,** the sporophyte is green, and it soon develops **roots** that supply it with water and mineral salts from the soil. As soon as this stage is reached the gametophyte shrivels and dies, and the sporophyte becomes an independent plant.

Advance of the sporophyte. In the life cycle of the fern we observe an alternation of generations similar to that of the bryophytes. However, we see in the fern plant a sporophyte that shows a marked advance beyond that of the liverworts and mosses. A closer examination of the fern sporophyte will reveal new developments that make the plants better adapted than the bryophytes for life in an aerial environment. The fern sporophyte continued to develop chlorophyll, a habit already begun by certain bryophyte sporophytes. True stomas were developed in the epidermis, permitting free gaseous exchange between the internal tissues and the air outside. Thus the fern sporophyte became a well-equipped food-manufacturing machine. A new differentiation of tissues took place, resulting in the development of a vascular system which provided the supply of water and mineral salts.

A microscopical examination of the stem and roots reveals the presence of vascular bundles with xylem and phloem. The establishment of a conductive system in the sporophyte marks an epochal change in the history of the plant kingdom and has been compared to the advent of the endoskeleton in the animal kingdom. Naturally, without some adequate conductive system, plants could not extend themselves very far above the soil, but when the vascular system appeared, sporophytes at once began to grow until in seed plants they eventually attained such proportions as those of the "big trees" of California. With the development of photosynthetic and conductive machinery, the sporophyte became well equipped for both food manufacture and spore production, leaving to the gametophytes only the function of producing gametes. For a time the gametophyte remains green and continues to manufacture its own food as in the fern, but we shall see subsequently that the gametophyte becomes more and more reduced until it is only a microscopic plant wholly parasitic on the sporophyte. In other words, in the developmental progress of the plant kingdom, gametophyte and sporophyte exchange

PLATE XXVI. Ferns. *a*, water fern, *Azolla*; *b*, shield fern. *Photograph a furnished by Ralph C. Benedict, Brooklyn Botanical Garden; b furnished by H. Lee Dean.*

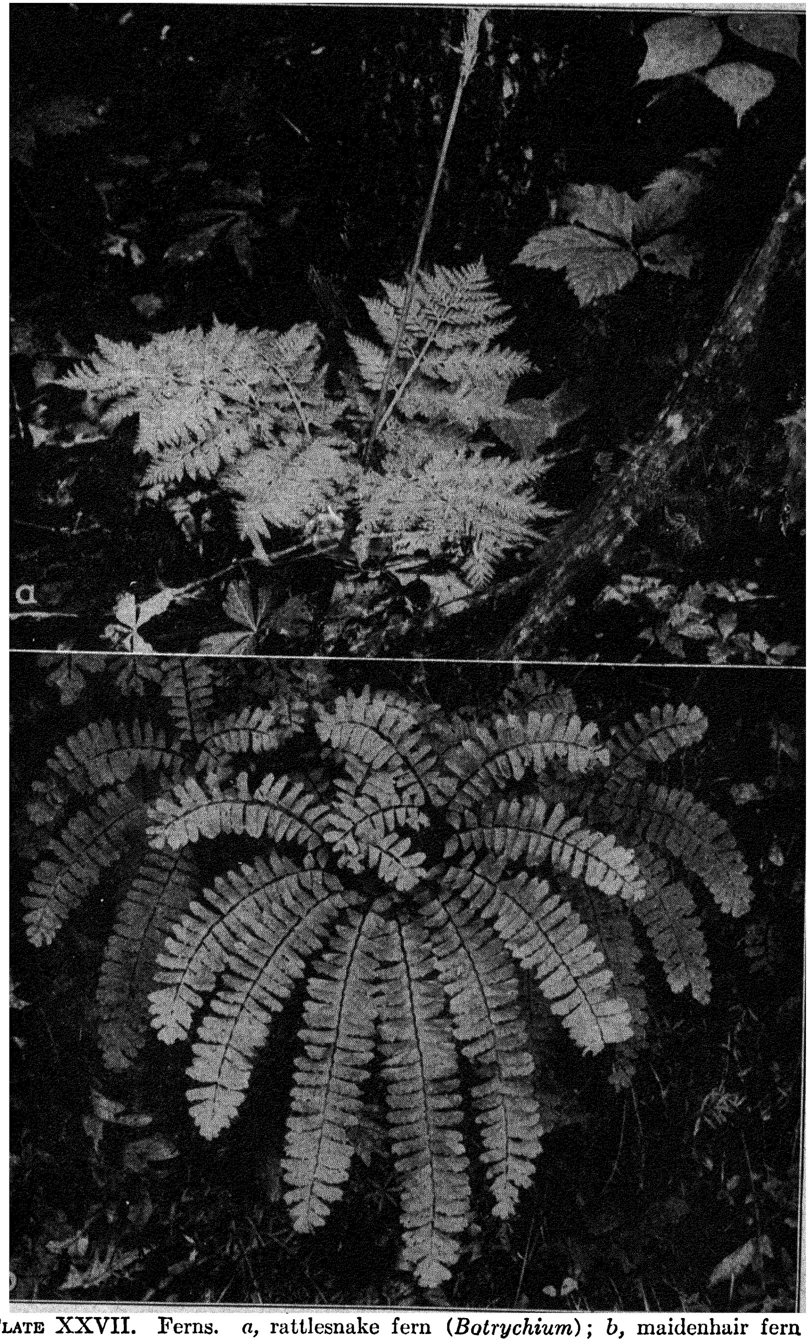


PLATE XXVII. Ferns. *a,* rattlesnake fern (*Botrychium*); *b,* maidenhair fern (*Adiantum*). *Photographs by H. Lee Dean.*

places in the order of their importance as conspicuous independent plants.

Equisetineae (*equus*—horse; *seta*—bristle) **or horsetails.** The modern horsetails usually have erect, columnar, jointed, fluted, green stems that arise from horizontal rhizomes. In some species, whorls of branches occur at each node, giving the appearance of a little bush or brush, which suggested the name "horsetail" (Fig. 304). Leaves are represented by small, functionless, pointed scales borne in sheathing whorls at the nodes. The cell walls contain considerable silica, which imports a harshness to the texture of the stem. The early settlers tied sections of these harsh stems into small bundles which were used as brushes to scrub tabletops, floors, tubs, and other utensils, hence the plant became known as the "scouring rush."

In the reproductive period, there appears at the top of the stem a small conelike structure called the **strobilus** (*strobilus*—a pine cone). It consists of a central axis with greatly shortened internodes, and at the nodes are whorls of lateral structures called **sporophylls.** Each sporophyll ends in a shieldlike plate that bears five to ten saclike sporangia containing **spores** (Fig. 304). Two coiled, ribbon-like **elaters** are attached to each spore, and since these are very hygroscopic, they aid in the dispersal of the spores, which, upon germination, produce thalli, the gametophytic plants. These gametophytes produce either antheridia or archegonia, depending on the vigor of the thallus. Apparently, the smaller, thin thalli develop antheridia, and the larger, thicker ones may develop both antheridia and archegonia. When the coiled, multiflagellate sperms are discharged from the antheridia, they swim to the archegonium, where one fertilizes the egg. The zygote develops in the same way as the zygote of the fern and gives rise to a new sporophyte which is dependent upon the gametophyte for only a very short period.

The living members of this group constitute but a poor, straggling remnant of a mighty pteridophyte group that flourished in the Carboniferous period (see page 572). During that period the *Calamites* —ancient relatives of modern *Equisetum*—formed extensive forests of trees that grew to a height of ninety feet, with trunks three feet in diameter. Except two or three tropical species, modern horsetails rarely exceed a height of three feet. One weak-stemmed species of South America, if supported by trees, reaches a height of forty feet. There remains only one genus, *Equisetum,* with about thirty species.

Lycopodineae or club mosses. This is probably the most ancient group of the pteridophytes, and our present-day forms represent but poorly the splendid lycopod flora of the Carboniferous period

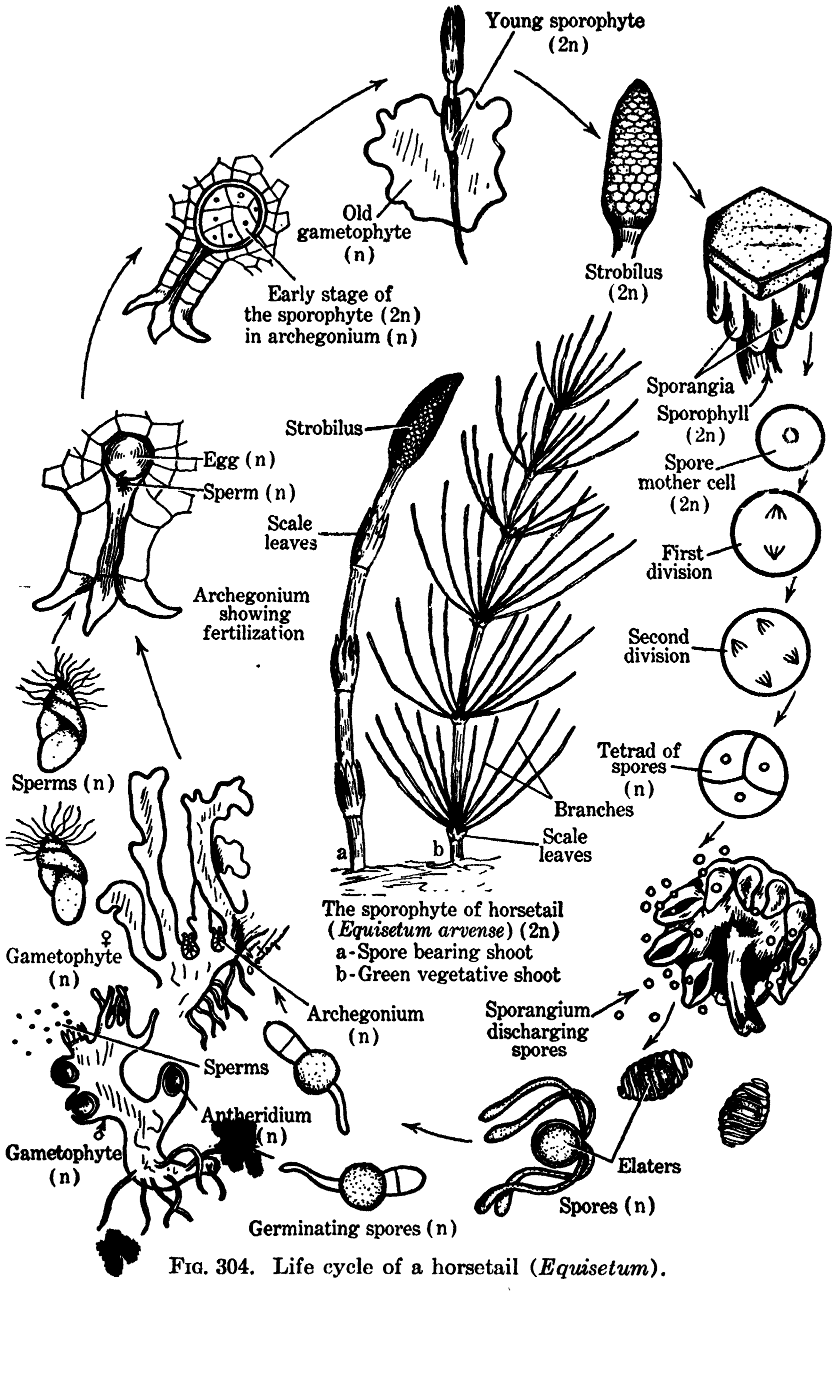


FIG. 304. Life cycle of a horsetail (*Equisetum*).

when these plants ranged from delicate herbaceous forms to giant forest trees. The modern lycopod sporophyte is a low, more or less herbaceous plant that bears numerous small, scalelike leaves (Fig.

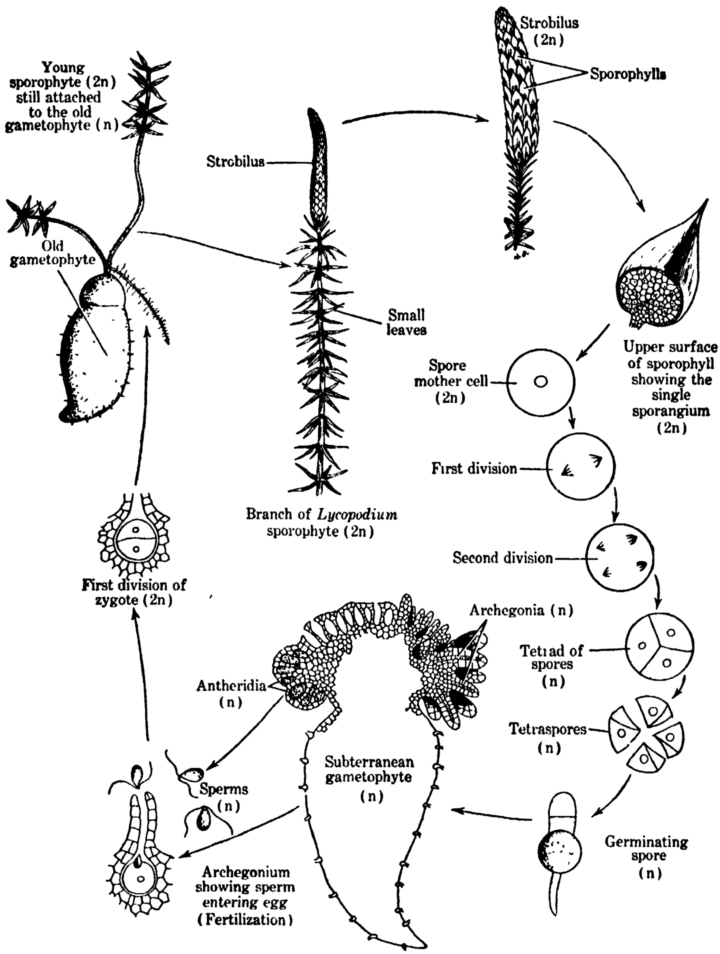


FIG. 305. Structure and life history of a club moss (*Lycopodium*).

305). The ground pine so much used in Christmas decorations is a good example of these plants. Some species of *Lycopodium* produce their sporangia singly in the axils of reduced and otherwise modified leaves called **sporophylls,** which are arranged closely about a central axis, forming a **strobilus.** The club-shaped appearance of the strobilus is responsible for the common name club mosses (Fig. 305). The strobilus is a structure of more than passing interest because it

is the forerunner of the flower. When the spores germinate they produce gametophytes ranging in form from thick, lobed, thalluslike structures to underground tuberous plants (Fig. 305). Each gametophyte bears both antheridia and archegonia. The sperms are biflagellate, a character that indicates relationship with the bryophytes. Fertilization takes place in the usual way, and a sporophyte arises which is dependent upon the gametophyte for a short time only.

In *Selaginella* there are two kinds of sporophylls in the strobilus, viz., **microsporophylls** (*micros*—small; *sporos*—seed; *phyllon*—leaf) and **megasporophylls** (*megas*—great). On the microsporophylls, **microsporangia** are borne, containing a very large number of small spores called **microspores.** Each megasporophyll bears a **megasporangium** containing four large spores called **megaspores.** The microspores begin to germinate while still in the microsporangium. This is a departure from the behavior of the spores previously studied but it becomes a fixed habit in the remaining phylum—the seed plants. The entire development of the male gametophyte of *Selaginella* is **endosporic,** i.e., it takes place entirely within the microspore (Fig. 306). When shed, the microspore contains one very small cell and a second large cell which undergoes a series of divisions resulting in the formation of a central group of cells surrounded by a single layer of wall cells. Each one of the central cells gives rise to a single sperm. This capsule containing the sperms is the mature male gametophyte, consisting of the wall cells, the sperms, and one very small, decadent, vegetative or prothallial cell which is thought to be homologous with the vegetative cells of the fern prothallus. This gametophyte is little more than an antheridium, and, of course, it is entirely parasitic on the sporophyte.

The megaspores also start germination before being released from the megasporangium. The nucleus undergoes a series of divisions but no walls are formed. By the divisions a large number of nuclei are formed, which assemble mostly in one end of the spore. Walls now begin to form simultaneously, giving rise to a mass of tissue within the megaspore, the female gametophyte, which also develops endosporically. As the gametophyte grows, it ruptures the old megaspore wall, thus becoming exposed. In the exposed gametophytic tissue, archegonia develop, and sometimes functionless rhizoids and chlorophyll may appear. However, the female gametophyte is parasitic upon the sporophyte.

In certain species of *Selaginella,* the mature microspores sift down between the megasporophylls and come to lie close to the megaspores. Then, if there is a rain or heavy dew, water will be absorbed by the

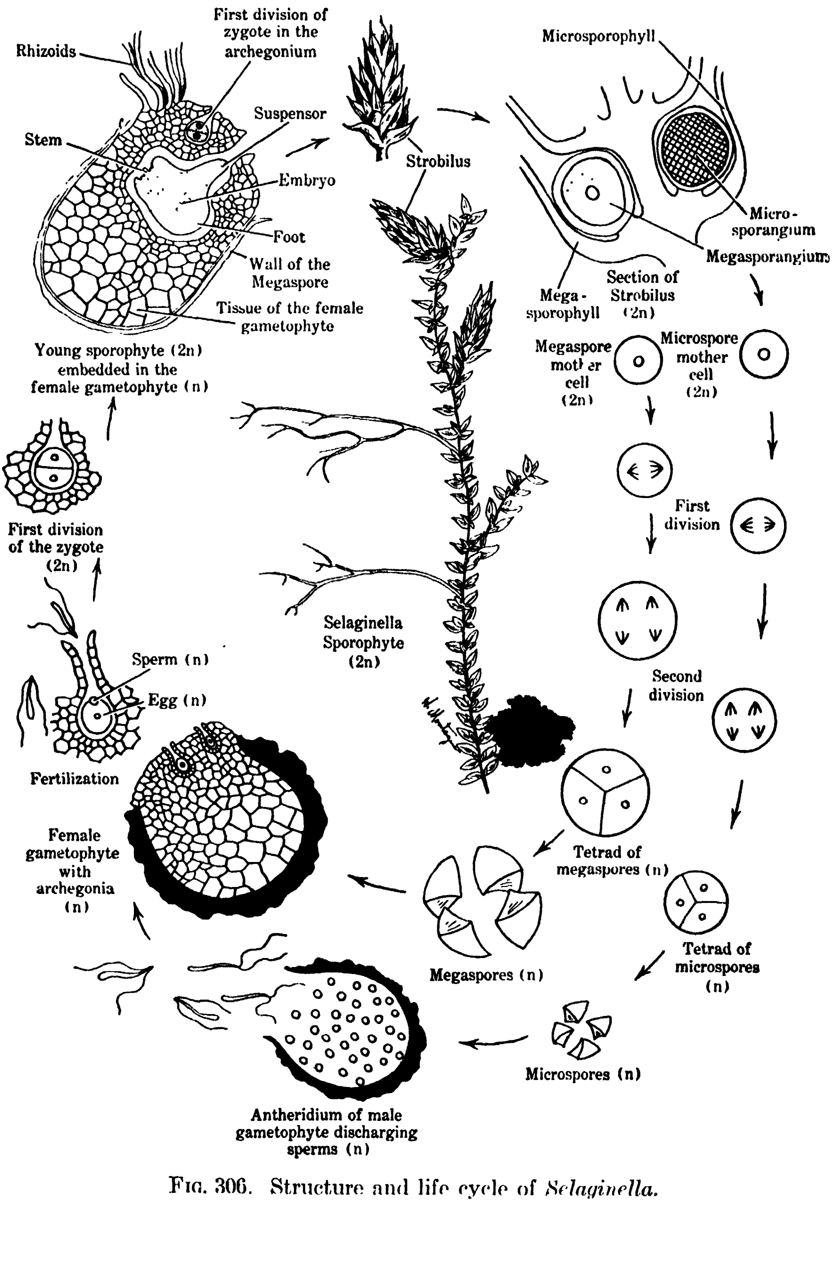


FIG. 306. Structure and life cycle of *Selaginella*.

microspore, which swells and bursts its walls, thus freeing the biflagellate sperms. With an abundance of water present, these sperms can swim to the exposed archegonia, where fertilization takes place. The zygote then develops an embryo which grows into a mature sporophyte. In some species, the megaspores are retained in the megasporangium not only until the female gametophyte is matured but on through the period of fertilization and development of the embryo, even up to the time when the root and stem of the new plant have emerged through the wall of the sporangium. This development of the female gametophyte and embryo within the megasporangium suggests how seed formation began, for, as we shall see, it is precisely what takes place in the seed plants.

In bryophytes, most of the ferns, horsetails, and lycopodiums, only one kind of spore appears in the life history. Therefore we speak of them as **homosporous** plants. *Selaginella* with its microspores and megaspores presents a striking new departure and inaugurates a type of spore differentiation which becomes definitely fixed in seed plants. Plants that produce dissimilar spores are called **heterosporous** plants. It has been observed that microspores produce the male gametophytes and the megaspores produce the female gametophytes. This is the behavior in the spermatophytes, and, since it leads to seed formation, **heterospory** has been spoken of as the forerunner of the seed.

In summarizing the contributions of the pteridophytes, first of all we note the development by the sporophyte of an efficient photosynthetic mechanism. In this same connection we have seen the development of a highly specialized vascular system and the differentiation of roots, stems, and leaves. This development released the sporophyte and made possible the growth of tall, terrestrial plants. We have seen the increasing decline of the gametophyte until it is little more than a microscopic antheridium concealed in a spore. In this group we catch our first glimpse of the strobilus, the forerunner of the flower, and also of heterospory, the forerunner of the seed. Thus we see that the pteridophytes are plants of outstanding scientific interest. Aside from their esthetic value as ornamental plants, they have practically no economic importance.

Pteridophytes of the past. We have seen that the great development of pteridophytes occurred during early geologic times when there were extensive areas of marshland in various parts of the world. These swampy areas supported a luxuriant growth of vegetation. At length conditions changed and this enormous mass of plant material was buried under layers of mud, sediment, and water, and consequently it was subjected to great pressure. Owing to oxygen

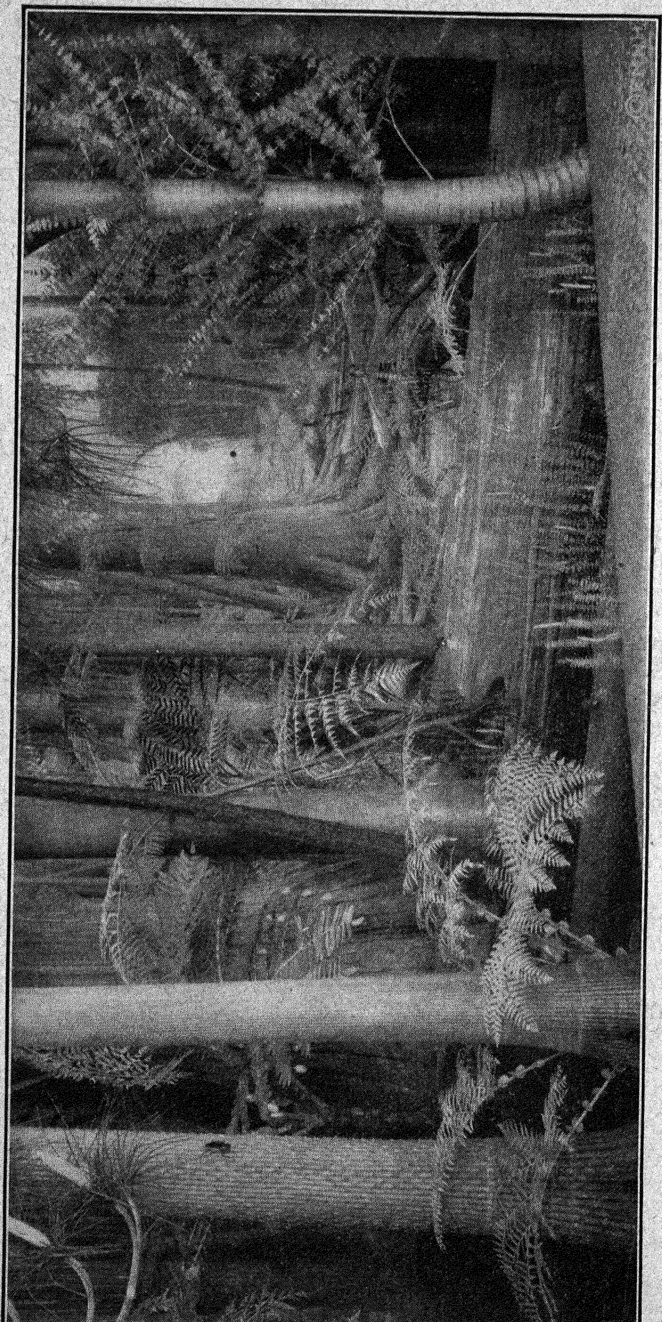


FIG. 307. Reconstruction of a portion of a carboniferous forest. The trees shown are primitive gymnosperms, giant horsetails (*Calamites*), and great club mosses. *Photograph by the Field Museum of Natural History, Chicago.*

deficiency there was little decay, and slowly the plant tissues were changed into various chemical compounds. Water, carbon dioxide, marsh gas, and other volatile substances escaped, and the remaining residue formed the coal deposits that are now being exploited.

It has been estimated that a bed of plant remains 300 feet in thickness was necessary to form 20 feet of coal. It has been shown that some coals were formed largely from the spores of some of the early pteridophytes and seed plants. Undoubtedly the great industrial development of the present century has been made possible by the contributions of prehistoric plants (Fig. 307).

PHYLUM SPERMATOPHYTA

(*sperma*—seed; *phyton*)

This phylum of the plant kingdom contains about 195,000 species —a greater number of species than there are in the other three phyla combined. It is set apart from the other phyla by the presence of **seeds.** The seed plants dominate the vegetation of the earth and are found in many very different habitats. In size, they range from tiny plants like the duckweeds, some of which are little larger than the head of a pin, to the "big trees" of California that grow to a height of more than 350 feet, with a diameter of 30 feet or more.

In this group we find the largest and the most highly specialized sporophytes. On the other hand, the gametophytes are microscopic, parasitic structures hidden away in the tissues of the sporophyte. The sporophytes are of the very first importance economically because either directly or indirectly man depends upon them for food. The spermatophytes are divided into two groups.

Gymnosperms (*gymnos*—naked; *sperma*—seed). Some of the best-known gymnosperms are pine, spruce, larch or tamarack, hemlock, arbor vitae, juniper, cypress, fir, and yew. The gymnosperms are by far the oldest group of seed plants, with a record that extends far back into the Paleozoic period. (See page 636.) In fact, our present-day gymnosperms, including 630 species, appear to be nothing but relics of a gymnospermous flora that was far more abundant in early geologic time than it is today. Whether these plants have descended from a primitive pteridophyte ancestry, or whether the pteridophytes and gymnosperms represent parallel lines of development from some earlier common stock, is still an unsolved problem.

We shall study the life history of pine as a representative gymnosperm. The pine tree is the sporophyte, comparable to the dependent sporophyte of liverworts and mosses, the fern plant, the ground pine, and other club mosses. The tall, woody trunk so valuable as lumber,

the evergreen needle leaves, and the seed-bearing cones (strobilus) are objects with which we all are more or less familiar. The pines

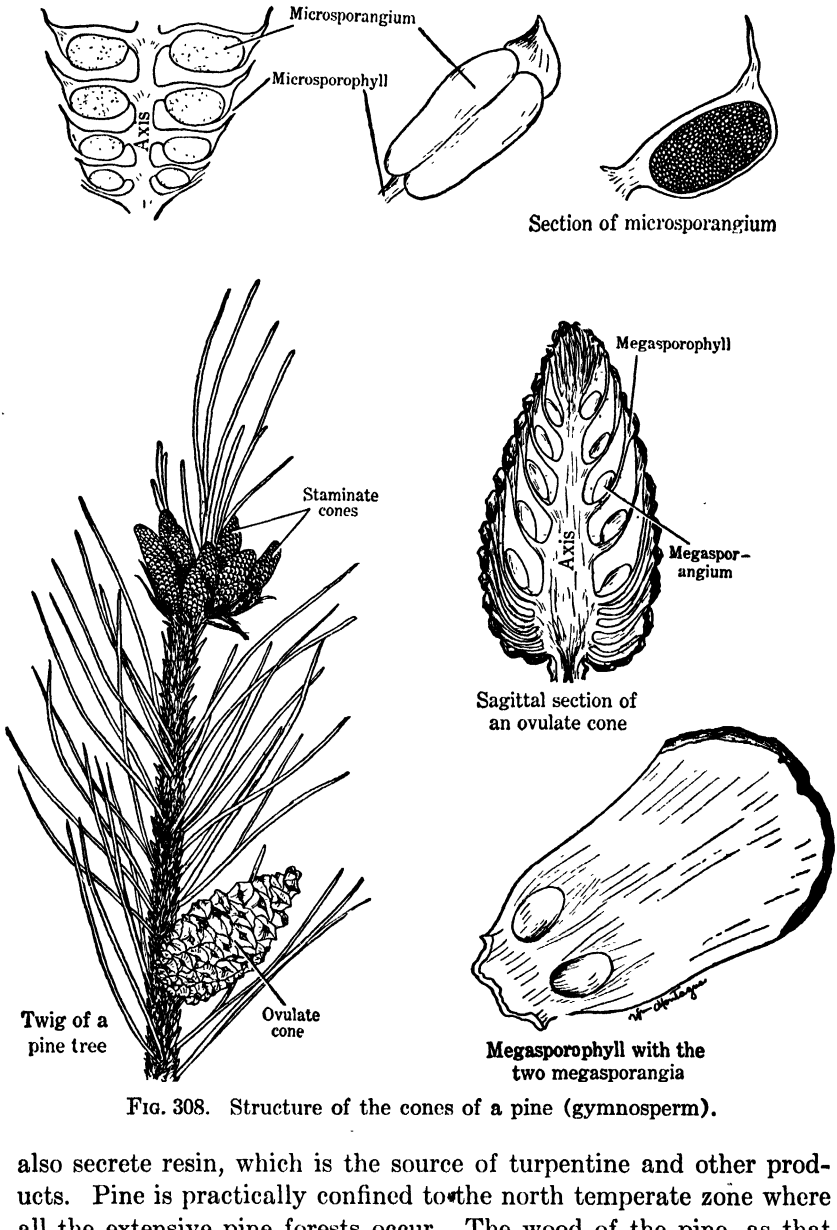


FIG. 308. Structure of the cones of a pine (gymnosperm).

also secrete resin, which is the source of turpentine and other products. Pine is practically confined to the north temperate zone where all the extensive pine forests occur. The wood of the pine, as that of the great majority of the gymnosperms, consists only of tracheids;

there are no vessels such as are found in the angiosperms. Unlike the phloem of angiosperms, the phloem of gymnosperms has no companion cells associated with the sieve tubes.

The pine is monoecious; i.e., both staminate and ovulate cones, sometimes called "flowers," are borne on the same tree (Fig. 308). As in the pteridophytes, the cones consist of a group of sporophylls arranged about a central axis. The **staminate cones** appear in clusters at the ends of the branches in late spring. They are more numerous, smaller, and more delicate than the **ovulate cones** and soon wither and drop off. The **microsporophylls** or **stamens** of the staminate cone each bear two **microsporangia** or **pollen sacs** (Fig. 308). Within the sacs, **microspores** or **pollen grains** are produced. The **megasporophylls** or **carpels** of the ovulate cone each bear two **megasporangia** or **ovules.** The ovule consists of a central mass of tissue, the **nucellus,** surrounded by an outer covering, the **integument.** Except for a little pore, the **micropyle,** opening toward the base of the scale, the integument completely encloses the nucellus. Since the **megaspores** are formed in the nucellus, it is the megasporangium proper. In gymnosperms, the ovule lies exposed on the surface of the megasporophyll, whereas in angiosperms the ovule is completely enclosed by the megasporophyll or carpel.

The microspore or pollen grain has two coverings, an inner delicate coat called the **intine** and an outer, heavy coat, the **exine.** It develops a **wing** at either side by the outgrowth of the exine, which becomes separated from the intine and extended by inflation. Germination begins while the spore is still in the microsporangium. Successive divisions give rise to four cells—two small **prothallial cells** which soon disappear, a large **tube cell,** and the **generative cell** (Fig. 309). At this stage in their development the pollen grains are shed and dispersed by air currents. Some of the pollen sifts in between the scales (megasporophylls) of the ovulate cones and comes to lie on the ovule (megasporangium) in the region of the micropyle (pollination). Some of the grains fall into a viscous fluid secreted by the nucellus and exuded through the micropyle. When this fluid dries up, the pollen grains touching it are drawn down through the micropyle and brought into direct contact with the nucellus (megasporangium). Here the development of the male gametophyte continues. Owing to the absorption of water, the protoplasm of the pollen grain swells and the exine is ruptured. The intine is then pushed outward, forming a little tube which grows into the nucellus. The large tube cell previously mentioned passes into this tube and

apparently regulates its growth, hence its name. The tube digests the tissue and grows deeper and deeper into the nucellus. The generative cell divides, forming a **stalk cell** and a **body cell.** The body cell soon moves into the tube, and there its nucleus divides, forming two **sperm nuclei.** The tube with its contents is the male gametophyte.

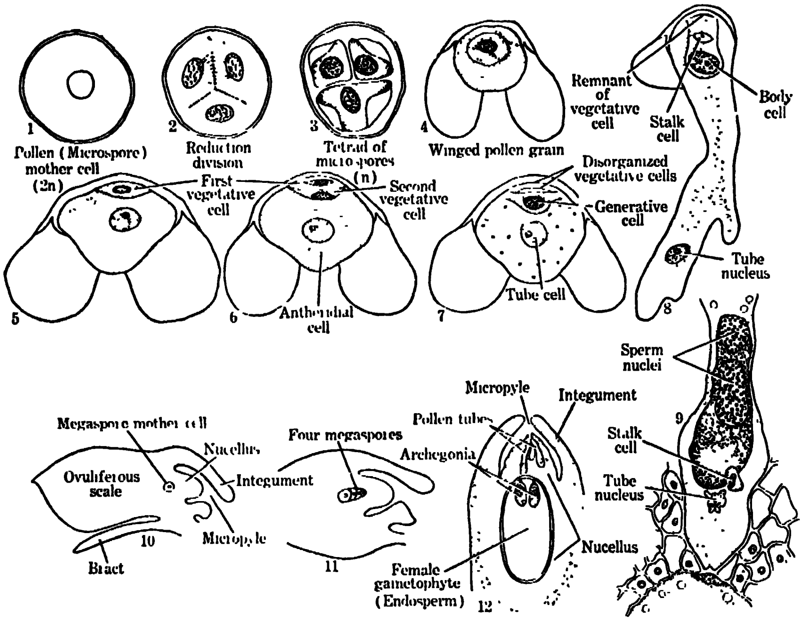


FIG. 309. Development of the male and female gametophytes of a pine. *After Holman and Robbins, "Textbook of General Botany." (Redrawn from Coulter and Chamberlain.)*

During the year after pollination, the development of the female gametophyte takes place within the nucellus. There is but one megaspore mother cell, and from this single cell four megaspores arise by divisions, the first of which is a meiotic division. Only one of these megaspores functions, and the entire development takes place within the megasporangium. The germination of the megaspore and subsequent growth give rise to an ovoid mass of tissue that has consumed much of the nucellus and occupies a large amount of the space within the integuments. This mass of tissue is the female gametophyte in which several archegonia, each containing a single egg, develop at the end nearest the micropyle (Fig. 309).

During the period in which the female gametophyte has been developing, the pollen tube has continued to grow until it has grown

through the nucellus and its tip now lies near the entrance to the neck of an archegonium. The nucleus of the body cell has divided, forming the two sperm nuclei **(microgametes)** which are carried by the streaming protoplasm into the tip of the tube. When the end of the tube ruptures, these gametes are discharged into the archego-

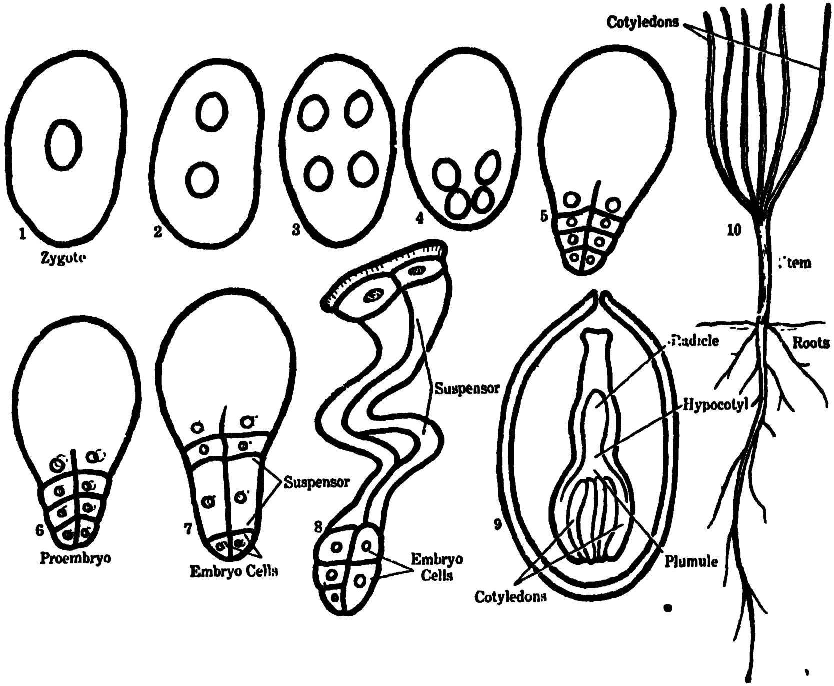


FIG. 310. Development of the embryo of a pine. The numbers indicate the sequence in development. *After Holman and Robbins, "Textbook of General Botany." By permission of W. W. Robbins and of the publisher, John Wiley & Sons.*

nium, where one of them fuses with the egg, forming a zygote. The remaining sperm nucleus, the tube nucleus, and the stalk nucleus soon become disorganized and form part of the food supply of the developing zygote.

For some time after fertilization the female gametophyte continues to grow at the expense of the nucellus until practically all is consumed. The zygote develops, giving rise by repeated divisions to a small mass of cells arranged in four tiers with four cells in each tier. This is called the **proembryo** (Fig. 310). The cells in the next to the lowest tier become very greatly elongated, producing a slender stalk,

the **suspensor,** which shoves the four cells of the lowest tier deeper into the tissues of the gametophyte, whence it gets its food for further development. Each of these four cells develops into **an embryo.** The cells of the two upper tiers remaining in the cavity of the original egg cell absorb food material for the developing embryos. Since a female gametophyte may develop as many as three archegonia, twelve embryos may be initiated within a single ovule. However, very soon, one of these embryos begins to grow more rapidly than the others and, digesting its competitors, becomes the one viable embryo of the seed (Fig. 310). The part of the embryo nearest the micropyle is the **hypocotyl,** which later gives rise to the **primary root.** At the other end of the axis is the **plumule,** which will ultimately develop into the stem and leaves. Surrounding the plumule are the seed leaves or **cotyledons**—several in number. When the embryo reaches this stage in development it becomes dormant. In the meantime the integument has become thickened and hardened, and the ovule with its contents has become a seed. Such a seed contains the representatives of three generations: the seed coat derived from the integument, representing the old sporophyte; the remains of the female gametophyte ("endosperm") or food supply; and the embryo or new sporophyte. When the seed germinates it will give rise to a new sporophyte or pine tree. Usually, it requires from two to three years after the first appearance of the ovulate cone to produce mature seeds.

The gymnosperms are exclusively shrubs and trees. The group is divided into seven orders, three of which are now extinct and known to us only through their fossil remains. Of the remaining orders, one is represented by a single surviving species, *Ginkgo biloba,* or maiden-hair tree, which occurs only as an ornamental tree. Swimming sperms occurred in all the orders that are now extinct, and they are present in *Ginkgo* and the living cycads, which are mostly tropical gymnosperms. Motile sperms have disappeared in the Coniferales, as we have observed in pine, which is a representative of this order. Gnetales is a small order of gymnosperms the members of which show some striking features, such as the loss of swimming sperms, absence of the archegonia in some forms, and the development of vessels in the wood of some of the species. In some respects the strobili of the Gnetales resemble the flowers of angiosperms.

Angiosperms (*angeion*—receptacle; *sperma*). Here belong the great majority of our economic plants and by far the greater number of species that make up the conspicuous and vitally important part of our flora. Angiosperms are the most modern and the most highly specialized plants. The oldest ones of which we have any

fossil record have been found in the Jurassic rocks (see page 636), but as to the origin of these plants we have as yet nothing but theories.

We have already studied the structure and traced the life history of such a plant as the plum, a representative angiosperm (see pages 261–276), and all that now remains is to note how this life history is related to the life history of pteridophytes and gymnosperms, for

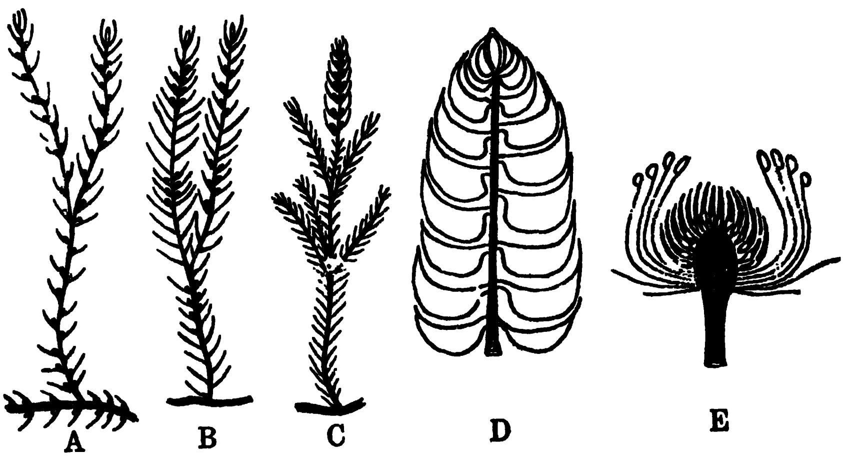


FIG. 311. Diagram showing the origin and development of the flower. *A*, extremely primitive type of strobilus, every leaf a sporophyll bearing sporangia. *B*, strobilus type, with leafy sporophylls composing the fertile regions alternating with the purely vegetative regions of the stem bearing the unmodified leaves. *C*, cone with sporophylls reduced and sharply differentiated from the vegetative leaves. *D*, extreme type of cone; longitudinal section of the staminate cone of conifers. Sporophylls much reduced, and sporangia all of one kind with leafy features entirely eliminated. *E*, primitive flower type with both mega- and microsporophylls present in the same general structure. *Redrawn from Hill, Overholts, and Popp, "Botany." By permission of the publisher, McGraw-Hill Book Co.*

a thread of similarity can be detected running through these groups, as is shown in the following table:

Selaginella	GYMNOSPERMS	ANGIOSPERMS
Strobilus	Cone	Flower
Megasporophyll	Scale of ovulate cone	Carpel
Microsporophyll	Scale of staminate cone	Stamen
Megasporangium	Nucellus of ovule	Nucellus of ovule
Microsporangium	Microsporangium	In anther of stamen
Microspore	Pollen grain	Pollen grain
Megaspore	Megaspore	Megaspore

A typical flower of the angiosperms is a modified strobilus with a perianth added (Fig. 311). In the more primitive flowers the perianth is omitted. Angiosperms and gymnosperms, like *Selaginella*, are heterosporous; in fact, we have seen how closely *Selaginella* approaches seed formation. We have also noted that in angiosperms the seed is enclosed within the carpel which gives rise to the fruit. We have emphasized this as an important distinction between angiosperms and gymnosperms, where the seed develops wholly exposed on the surface of the carpel and no fruit is produced. We have also observed that double fertilization takes place in angiosperms, giving rise to a new kind of tissue, the endosperm, which stores food for the embryo. In gymnosperms the embryo is supplied with food by the female gametophyte, sometimes called "endosperm."

As was noted previously, angiosperms are divided into two classes: dicotyledons and monocotyledons. In the final analysis, it is difficult to distinguish between these two groups, yet in general they are strikingly different. As the names imply, there is a difference in the number of cotyledons. Differences also occur in the plan of the vascular system and in the disposition of the veins in the leaf. In general, there are floral differences; e.g., the different flower parts of monocotyledons usually occur in threes or multiples of three, whereas in dicotyledons the basic number is generally four or five. For the most part, monocotyledons are distinctly herbaceous plants. From all lines of available evidence, the dicotyledons appear to be the oldest angiosperms and the monocotyledons the most modern, being descendants from a dicot ancestry in relatively recent geologic time.

It is impossible to consider here any large number of the many families of angiosperms, but a few interesting facts may be pointed out. The bulk of our timber is produced by a group of families low in the evolutionary scale of the dicots and known collectively as the Amentiferae because they produce some or all of the flowers in flexuous, scaly, pendent spikes called **aments.** Here belong the poplars, willows, oaks, chestnuts, beeches, birches, hickories, and walnuts. This group also supplies us with many of our favorite nuts. The cereals, such as oats, wheat, rye, corn, millet, rice, barley, and speltz, belong to the grass family (Gramineae), which is, without question, the first and most important food-producing family for both man and beast. The legume family (Leguminosae) is another very important food-supplying family, giving us beans, lentils, clover, alfalfa, vetch, and soybeans. The potato, tomato, eggplant, and tobacco belong to the nightshade family (Solanaceae). The family that provides the bulk of our fruits and many ornamental plants is the rose family (Rosaceae) including apples, pears, quinces, peaches, cherries, plums, apricots, raspberries, strawberries, and blackberries. Melons, cucumbers, squash, and pumpkins are contributed by the gourd family (Cucurbitaceae). Many other families supply articles of food or useful products of great value.

CHAPTER XVII

HOW ARE LIVING ORGANISMS RELATED TO THEIR ENVIRONMENT? ECOLOGY

The relationships between living organisms and their surroundings make up the subject matter of **ecology** (*oikos*—house; *logos*—discourse). If we were to make a hasty review of the many phases of plant and animal behavior discussed in the previous chapters, we would reach the conclusion that ecology is a broad and inclusive subject, and that any brief presentation will be very inadequate.

The leading physical factors of the environment. In the environment of an organism, the sum total of the factors that influence it in any way constitutes its **habitat.** The physical factors of the environment that most influence living organisms are light, temperature, moisture, air, and the chemical and the physical nature of the soil. For all animals and non-green plants, food supply must also be included. At the very outset, it should be emphasized that the various factors of any environment are so closely interrelated that it is frequently difficult and sometimes impossible to determine the exact influence of any one factor acting independently of the others. It will be impossible to undertake a detailed study of the role and interactions of all these factors, but we shall consider briefly the influence of light, temperature, and water on plant and animal life.

LIGHT. Light is one of the most important factors affecting the structure, growth, and behavior of plants. Besides its role in photosynthesis, light exerts many other influences. It is necessary for the synthesis of plant pigments. It influences the position of the chloroplasts in the leaf as well as the form and internal structure of the leaf. Leaves exposed to full sunlight are usually thicker than leaves of the same plant growing in the shade. Moreover, there is a greater development of palisade tissue and the chloroplasts are arranged in line with the direction of light, thus reducing the amount of radiant energy absorbed. We have already seen how leaves respond to light by assuming the most advantageous position. It has also been pointed out that light influences both the production and

transport of plant hormones, the agents of growth regulation that induce phototropic responses.

Competition with respect to any one factor can be well illustrated by observing the adjustments of plants to light. The tallest individuals of any plant community receive the most light. Thus, in any developing forest, the tree seedlings elongate rapidly and compete with one another for the available light. Lianas or climbing plants, such as the wild grape and woodbine, climbing on the trunks and branches of trees, require very little supporting tissue of their own; therefore they can elongate very rapidly, bringing their leaves into position where they can compete for light with the leaves of trees.

We have previously indicated that light also affects animals either indirectly by influencing their food supply or directly by altering their physiological processes and certain structural features. Photoreceptors, such as pigment spots and eyes, have developed as an adaptation to light, thus enabling the animal to explore better its environment, to procure its food, or to evade its enemies. The photoreceptors probably play a part in the recognition of mates during the breeding season. They also function in the formation of color patterns. For example, the mottled pattern of the flounder not only changes its shades of color but may even take on the same mottled appearance as the sand or gravel on which the fish is resting (Fig. 332). Similar changes in color pattern occur in the skin of the frog and chameleon. These changes, taking place instantaneously or quite slowly, are brought about by the spreading or concentration of the pigment in certain parts of the pigment cells.

Reproductive activities in some animals undergo various modifications in response to changes in the duration and intensity of light. Poultrymen increase the egg production of hens by exposing them to longer light periods. An important effect of light is seen in the development of vitamin D through exposure to sunlight. Children supplied with an abundance of sunlight seldom suffer from rickets. When spotted cattle exposed to direct sunlight are fed on buckwheat, a rash develops on the skin of the white spots. As the disease progresses, the skin affected scales off, a fever develops, and the animal dies. White mice kept on a buckwheat diet thrive in a dark room, but in bright light they quickly die. Evidently buckwheat contains materials that render protoplasm sensitive to intense sunlight. Apparently, life in direct sunlight is made possible only by some protective adaptations. For example, the salamander *Proteus*, when exposed to continuous light, first becomes brown and then black.

The human skin develops more pigment (tans), which protects it from injury caused by the rays of the sun.

In their habits organisms become adjusted to light. We have previously mentioned the photeolic movements of leaves. It may be added that in some plants such as *Nicotiana* and the night-blooming cereus the period of blossoming coincides with the period of darkness. In dandelion and most other plants blossoming takes place during the hours of light. Among animals there are the nocturnal forms, such as the cockroach, bat, owl, and flying squirrel, and the more extreme example of termites that live in dark tunnels in wood entirely excluded from the light. The caterpillar feeds in the sunlight but avoids light when it pupates.

TEMPERATURE. For every organism there is a range of favorable temperatures within which life processes go on smoothly. Below the lower limit of this range, or minimum temperatures, and above the upper limit, or maximum temperatures, the activities of the organism cease. The optimum temperature is that at which the organism thrives best. Minimum, maximum, and optimum temperatures vary with respect to different organisms, but the minimum must generally be slightly above 0° C., since water freezes at this point, and the maximum usually falls in the neighborhood of 60° C. In certain organisms the range may extend beyond these limits.

Adjustments to temperature involve modifications of both structure and behavior. The temperature of plants, like that of cold-blooded animals, fluctuates with the temperature of the environment, yet at the approach of winter many plants undergo changes that apparently protect them against low temperature. In the northern latitudes many plants convert their food reserves of starch into fats and oils. Emulsoids of fats or oils and water can be cooled below 0° C. before ice formation occurs. Often during fall and early winter there is an increase in the osmotic pressure of the cell sap, which also lowers the freezing point. In many plants, water-retaining substances, such as mucilages and pectic bodies, develop that help to prevent the desiccation incident to low temperatures. Even the proteins of the protoplasm in hardy plants may be changed to soluble forms in which they are less easily precipitated.

In the arctic regions, animals like the arctic fox, seal, and polar bear are well protected by heavy pelage and also by a thick layer of fat. Many of the arctic forms and some temperate-zone forms, such as woodchucks, reptiles, insects, and mollusks, hibernate in winter. During the dry seasons of summer, certain of the insects, spiders, crocodiles, turtles, snakes, the aardvarks, and the lemur

estivate. An estivating snail from the border of the African desert "came to life in the British Museum" after a period of five years. As a rule, temperate-zone and tropical animals have less heavy coats, are of a darker shade, and are often more brilliantly colored.

Some extreme cases of temperature adaptation are known. The "black spot" fungus thrives on meat in cold storage. It grows and will even produce spores at a temperature of 6 degrees below 0° C. Certain crustaceans and insect larvas are found living in hot springs with a temperature range of 50° to 60° C. On the other hand, burrowing through the arctic snows are earthworms feeding on algae. Many animals escape extremes of temperature by making seasonal migrations, and they will be found in tropical, temperate, and arctic regions at different times of the year. As we shall see later, temperature is an important factor in the distribution of animals and plants.

WATER. Life doubtless originated in the water. In fact, the maximum size of animals has been attained in the sea, at once suggesting that water is an ideal habitat. The moisture in the atmosphere, or atmospheric humidity in the environment of land dwellers, is an extremely important factor.

Water has a greater influence on both the external and internal structure of plants than any other factor. According to Schimper, "The type of vegetation in the tropical and temperate zones is determined by the amount and seasonal distribution of the rainfall and by the humidity of the air."

Plants may be classified with respect to water. Plants adapted to extremely wet situations, e.g., pond weeds and bulrushes, are **hydrophytes;** plants of dry habitats, e.g., cacti and sage brush, are **xerophytes;** and such plants as ginseng and maple trees, thriving in habitats characterized by a medium moisture supply, are **mesophytes.**

Animals inhabiting the water do not require skeletons as strong as those of land animals, and they are usually cold blooded and more sluggish. They range from free-swimming to floating forms. The capacity to float is made possible by the production and retention of gas bubbles, oil globules, or jellylike substances. The sessile habit of animals has been developed only in an aquatic habitat. Among the major adaptations of the aquatic vertebrates for their mode of life are the commonly streamlined body and the modification of the organs of locomotion. In fishes these organs are the flattened tail and fins. Following this general pattern, the tail is flattened, as in the whale, the alligator, and other aquatic reptiles. The lateral appendages of the whale and seal appear as flippers, and the wings of the penguin are modified to form swimming organs. Because of the

general stability of the environment, i.e., the relatively constant temperature, the comparatively uniform concentration of dissolved gases and inorganic salts, and the unvarying food supply, the animals of the sea are less progressive and show comparatively little variation.

Adaptation. The chief business of each plant and animal is to establish and maintain the most harmonious and balanced relationship with its own peculiar habitat. When an organism *fits* into its environment, it is said to be adapted to that environment. Such adaptation is not necessarily the result of conscious effort on the part of the organism. It may be the result of heredity, or of the influence of special factors, or of the accumulated effects of past experience, or of other conditions and correlations of which we have little or no knowledge.

Adaptation is rarely perfect. Some organisms are very poorly adapted to the environment in which they are obliged to live. However, every organism is able to modify to some extent its structure or function, or both, in response to ordinary changes in its environment. Whenever a species loses the capacity to adjust, or ceases to use it, that species becomes extinct. Since all habitats are constantly changing, it follows that the organism must keep making continual adjustment and readjustment if it is to maintain any approximate equilibrium with its habitat. This means that every living organism is engaged in an active, perpetual, unceasing struggle for adjustment that can be terminated only by death. From the viewpoint of biology, *only that organism or race is successful that can maintain itself and its kind in a favorable environment* or in an environment to which it can adapt itself. Each habitat sets the limits within which adaptations of the organism may be effected and thus shapes both the structural and the dynamic or functional pattern of the plants and animals living there.

In all organisms, regardless of how it came about, there is an inherited fitness for a particular kind of habitat; this fact in general explains why animals and plants live where they do. Thus we find desert plants that cannot thrive in the forest, trees that cannot grow in the water, and water plants that cannot grow in the desert. Similarly, there are marine animals and fresh-water animals; subterranean animals and aerial animals; pelagic animals, i.e., animals that live far from shore, and littoral animals, i.e., animals of the shore waters and beaches. In considering the land habitat of animals, we meet variable conditions with respect to water supply, respiration, substrate for locomotion, temperature, flora, and food conditions. As has been pointed out previously, a watery habitat offers much more

stable, uniform conditions than the land. We have already considered adaptations to water supply, temperature conditions, and food. Locomotion on land is effected mainly by crawling, walking, and flying, or by a combination of all these methods. Snails, slugs, and snakes crawl, whereas most vertebrates, except fishes, walk or fly. The feet of various animals are modified in accordance with the type of substrate of the habitat. Thus the toes of wading birds are

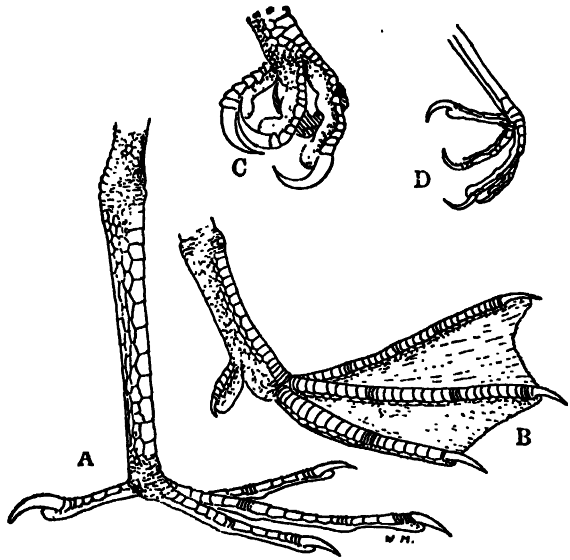


Fig. 312. Adaptations and specializations of feet of birds. *A*, wading bird; *B*, swimming; *C*, grasping; *D*, perching. *From Strausbaugh and Weimer, "Elements of Biology," published by John Wiley & Sons.*

long and slender (Fig. 312). Many animals of the plains are equipped with hoofs, which in the mountainous forms are quite sharp and chisel-like. The caribou of the north has a wide spreading hoof that functions somewhat like a snowshoe. The great cats have padded feet which enable them to move quietly through the forests and tall grass to stalk their prey.

Many land forms spend most of the time in the air and in trees, a type of life likewise involving certain modifications. Thus there are certain frogs, especially in the tropics, whose toes are equipped with suckerlike disks that enable them to climb about in the tops of the highest trees. Some mammals, such as flying squirrels and certain lizards, glide from tree to tree by means of folds of skin which extend from the fore to the hind limbs. Monkeys swing from branch

to branch by means of slender, prehensile tails and grasping hands and feet, whereas winged flight is practiced by most birds and insects. Both structural and physiological adaptations are so numerous that nothing like a complete list can be given in this discussion.

Since many organisms have similar needs with respect to one or more factors such as light, water, food, temperature, and air, there

FIG. 313. Adaptations in animals. The two-toed sloth, a tree-dwelling mammal. *Photograph by the National Zoological Park.*

will be lively competition among them whenever they chance to develop a more or less crowded population within a limited territory. The competition and the necessity for adjustment to an ever-changing environment is met by organisms in three different ways: partial or complete adaptation may enable the organism to maintain itself successfully; the organism may migrate to a more favorable region; or, finally, the organism may fail to make an adequate adjustment, and die. Keeping in mind the enormous output of spores and seeds by plants, and spermatozoa and ova by animals, as well as the power of regeneration and vegetative reproduction, we can easily understand how the law of overproduction is operative and how intense the struggle for existence must be wherever living forms thrive under

favorable conditions. It follows then that, in all these densely populated regions, the organism meets keen competition, which constitutes a very important factor in determining the distribution of, and mode of life among, living organisms everywhere.

BIOTIC COMMUNITIES

In our study of biology, we have learned that inorganic materials and organic materials become organized to form protoplasm, that protoplasm is organized in the formation of cells, that cells are organized in the building of tissues, that tissues are organized into organs, that organs are coordinated in systems, and that systems are organized into organisms. Now we shall learn that the principle of biological organization extends even farther than this, and that organisms become organized into groups or communities.

Biome. In nature, plants and animals do not occur as scattered individuals but tend to form communities. In any given area there will be a community of plants and animals and not two separate communities, that is, one composed of plants and the other of animals. Such a plant-animal community is called a **biome.** In every biome, there is an interrelationship among its component organisms, i.e., there are many and varied interactions between plants and plants, between animals and animals, and between plants and animals.

Because of the interrelationship of its members, the biome is regarded as a complex organism or superorganism. In other words, we might call the biome a societal organism. In its original development and structure the biome is the result of the habitat that has produced it; i.e., the habitat is the cause and the biome is the effect. Such a concept takes into account not only the influence of the physical factors upon the organisms of the biome but also the reverse influence of the organisms upon these physical factors, or their **ecological reactions.** In contrast to the ecological reactions, the influences which the organisms of the biome have on one another are called **coactions.** As will be subsequently brought out, the ecological reaction of any community is something more than the sum of the reactions of its component individuals. For example, in the forest the litter which ultimately forms the duff and leaf mold is the product of each individual tree, but the total accumulation of fallen leaves and twigs is made possible by the close stand of many trees, arresting the action of winds that would otherwise remove most of this material.

FIG. 314. Distribution of the climatic plant formations of North America.

Climatic formations. According to their temperature requirements, plants and animals are distributed in great regional groups, each of which is restricted to a geographic zone. Thus there are arctic, temperate, and tropical floras and faunas. Within these regional areas, and also determined by climatic influences, are such groupings as the northern coniferous forest, prairies, and the northeastern deciduous forest. These are **climatic formations.** In North America nine climatic formations are recognized, each of which comprises a number of different kinds of communities (Fig. 314). Such classifications are based on the present distribution of animals and plants, but how they came to be best adapted to some particular set of conditions is another story. Within the larger regional and climatic groups are more restricted groupings or communities characteristic of the various habitats involved. Each such habitat has a characteristic group of plants and animals that do not represent "chance assemblages" but are to be regarded as "more or less closely interwoven communities." Just as each plant and animal is a balanced physiological system within the community, so is each community a system of plants and animals (biome) that tends to maintain a balanced relationship within itself and with its environment.

Plant and animal associations. Plants that can thrive together and adjust themselves continuously to the same general environment form what is known as a **plant association.** Animals often make use of plants and plant communities as breeding places and for shelter. This together with the fact that animals depend either directly or indirectly upon plants for their food, some requiring one kind of food and some another, would naturally lead to the inference that particular kinds of animals will be found in a particular plant community. Even a superficial study of the animal and plant life of any region will reveal the correctness of this inference.

When we study animal communities, we find three main categories based on the type of habitat: the **terrestrial,** the **aquatic,** and the **parasitic.** These main groups, in turn, may be divided into smaller communities each within its own peculiar habitat. For example, on the temperate grassland regions of North America we find such animals as the antelope, the coyote, the jack rabbit, and the prairie chicken, and, before man disrupted the faunal life, herds of buffalo. In somewhat similar manner we find a fauna peculiar to tropical rain forests, tropical grasslands, the deserts, the arctic tundra, the alpine regions, and other divisions.

Zonation. Around a pond or lake, zonation of plant associations may be seen (Fig. 315). In the shallow water may be a pondlily

zone; back of this a cattail zone; next a sedge zone; and last a zone of grasses. Or, in a wooded area, the sedge zone may be followed by a shrub zone, and this in turn by a tree zone. Each zone supports its characteristic population of animals.

In ascending the slope of a high mountain, one can observe a zonation comparable to that which one would find in passing from the equator toward the poles. Since changes in altitude, direction of

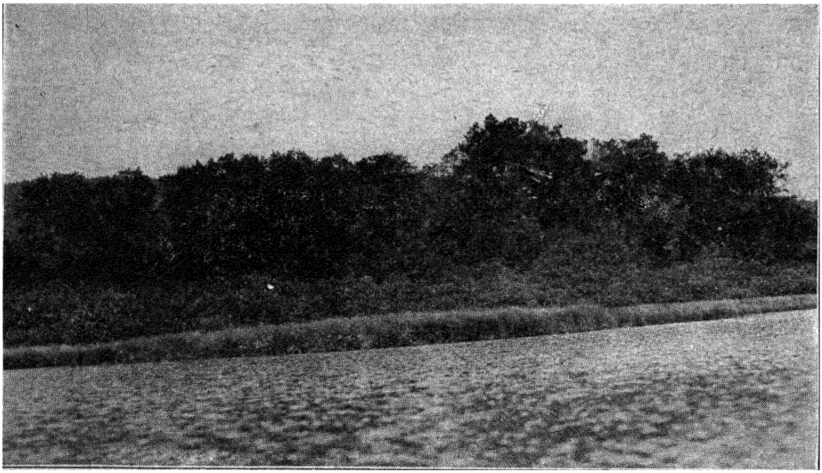


FIG. 315. Zonation. In the foreground back of the water's edge is a zone of rushes and sedges. Back of this is a belt of shrubs, and back of the shrubs is the tree zone. *Photograph by W. F. Rumsey.*

slope, and distance from the equator involve changes in temperature, light, moisture, and other factors, it is evident that the type of life found in these different situations will vary accordingly. If one ascends a mountain located in the tropical region, one will find tropical vegetation and animal life at the base and lower levels of the mountain slope. Higher up, there is a temperate-zone flora with deciduous trees sheltering a temperate-zone fauna. Still higher, trees do not grow, and here the plants are herbs, low shrubs, grasses, and sedges—an association somewhat resembling that of the arctic tundras. In this high montane region there is also a characteristic alpine fauna. In different regions this fauna is represented by such forms as the mountain sheep, ibex, chamois, yak, and condor.

Plant and animal distribution. With plants and animals alike, the distribution found today cannot be explained entirely on the basis of existing conditions. Geology teaches that in the history of

the earth there have been elevations and subsidences of different regions of the earth's crust, floods, glaciation, and great shifts of the climatic zones. All these changes have left an impress on the distribution of living organisms over the surface of the earth. Fossil evidence shows that, during late Cretaceous time, great dinosaurs ranged northward into Alberta and Mongolia, and such tropical and subtropical species as figs, breadfruits, cinnamons, and tree ferns flourished in Greenland. Cycads, palms, and figs were abundant in Alaska. Such facts furnish indisputable evidence that the climate

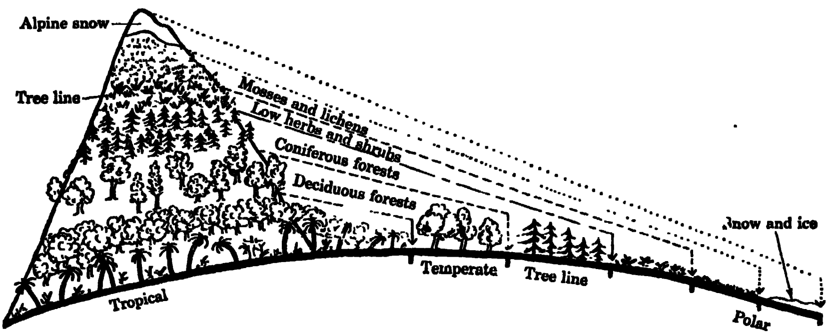


FIG. 316. Diagram showing distribution of plants as influenced by altitude and latitude. *Redrawn from Storer, "General Zoology," by permission of the author and the publisher, McGraw-Hill Book Co.*

of this period was more mild and equable over most of the land surface of the earth than it is at the present time.

Each species has originated in some specific place and, from this center of origin, has migrated in all directions as far as environmental conditions permitted. Thus eastern Asia is the center from which the genera *Acer* (maple) and *Rhododendron* have migrated. Doubtless Asia is also the center from which man has spread over the entire earth. The more favorable habitats have served as convenient highways along which the migration has taken place most rapidly. The unfavorable regions such as high mountain ridges and large bodies of water have been barriers to the spread of the species. The migration of species into a new territory brings about an increase in competition which, as we have seen, is a very important factor in determining the distribution of organisms. Therefore, the problem of explaining the distribution of both plants and animals is a difficult one, involving conditions and experiences of the past as well as of the present.

When man interferes with the natural distribution of plants and animals, new relationships are set up that often bring far-reaching consequences. The introduction of a new fruit or a new grain may mean the bringing in of a new fungus or insect parasite. Sowing a new kind of grass seed may introduce new weeds that may multiply and replace the grass. The weeds may furnish food for some insect that is injurious to some other species. Such changed relationships

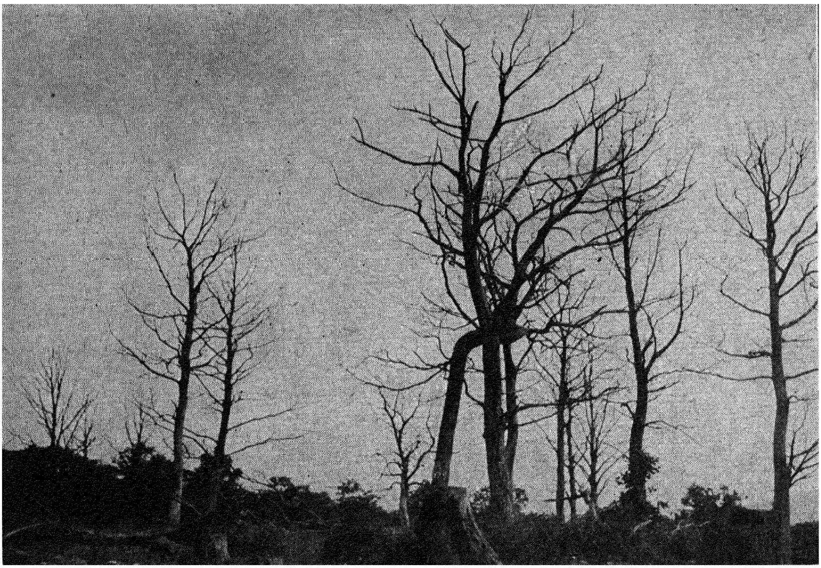


FIG. 317. Ravages of the chestnut blight. *Photograph by W. E. Rumsey.*

may involve a whole chain of coactions whose ultimate results cannot be predicted. A species living in a certain region often has its natural enemies to hold it in check. However, if this species is moved into another region where its enemies do not exist, it may become a serious pest. Examples are seen in the multiplication of the English sparrow and the starling when introduced into this country from England and in the plague of rabbits in Australia when these animals were introduced. Whenever there is any thought of introducing any species from one country into another, the possible consequences should be carefully considered. The chestnut-blight fungus has long been known in Japan, where it does little damage to the native chestnut trees. In 1904, the disease was introduced into this country, perhaps through the importation of some goods from the Orient; and in about twenty-five years the native chestnut trees were prac-

tically wiped out (Fig. 317). Such chains of coactions have brought about the introduction of both state and national quarantine regulations as a measure of prevention or control.

BIOTIC SUCCESSION

In the development of the biome many complex changes take place. In order that we may acquire some appreciation of them we shall discuss plant activity first and then return to the animal phase later. Plant life must always have its start on some bare area, first invaded by seeds or **propagules** of some kind such as the soredia of lichens or the spores of fungi. If they find favorable conditions, they will grow and form the first plants of the area. The successful adjustment of a plant to a new home is known as **ecesis** (*oikos*—home). It involves germination, growth, and reproduction. As individuals multiply there is an **aggregation** of plants forming a **family.** If other species migrate into the region, as usually happens, there will soon be a mingling of families forming a **colony.** Thus we see that **migration, ecesis,** and **aggregation** represent the earliest activities in the development of a plant community.

Even in the very earliest stages, it is apparent that reaction is taking place. The young community is altering the conditions of the habitat. There is increasingly more shade and consequently less evaporation. The root systems are changing the physical structure of the soil, and other influences are setting up new conditions. As these reactions continue, the habitat will become increasingly more favorable for other species that will eventually replace the older ones. In time, a new plant community will appear. Thus, as vegetation develops, continuous change is taking place so that any given area will be occupied by a succession of different plant communities. This change is known as **plant succession,** but we shall see that animals are also involved and therefore we may speak of **biotic succession,** a broader term covering both kingdoms. Each stage in the development is known as a **sere.** So long as the reactions cause a disturbance in the equilibrium between the organisms and the environment, succession will be continued. Once a sere is developed in which the reactions maintain a relative equilibrium with the environment, further succession ceases. The terminal sere of the succession is called the **climax stage.**

If we trace the development of vegetation on some bare area from its very beginning, we can form some picture of the dynamic struggle involved in the establishment and maintenance of a plant popula-

tion. A nude rock surface cannot support many kinds of plants. The pioneers to settle first on the rock are the crustose lichens (Fig. 318). They secrete organic acids which corrode and etch the rock so that the plants become imbedded. Great numbers of these lichens grow and die, and as they decay slight amounts of humus are formed. The humus holds moisture, making conditions favorable for the growth of foliose lichens. These larger plants add more humus, and

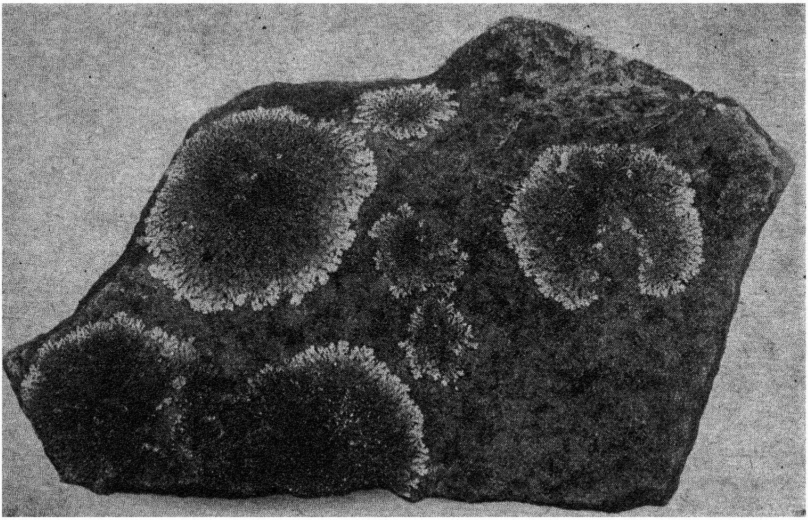


FIG. 318. Crustose and foliose lichens on a rock; a source of humus. *Photograph by courtesy of the New York Botanical Garden.*

more moisture is accumulated, until finally mosses gain a foothold. The mosses die and decay, adding more organic matter. As the mosses become established, the lichens are crowded out, and, as a result of this competition, the appearance of the vegetational cover changes. At length sufficient soil has accumulated on the rock to support some ferns and seed plants. With the advent of taller plants comes shade. Evaporation is checked, and moisture accumulates more rapidly. As conditions become more and more favorable, some shrubs will be established and eventually tree seedlings will appear. Thus we see that each stage (sere) established prepares the way for the ensuing stage.

The first tree seedlings that appear in the succession will be those that can grow in full sunlight, such as oaks or pines. However, when these trees have grown to maturity, forming a forest, they cannot reproduce their own kind because the seedlings will not thrive in the

dense shade of the parent trees. If the seedlings of maple, beech, or hemlock chance to develop here, they will grow successfully because they are shade tolerant. Now, as the older trees die and decay, they will be replaced by one or more of the new species, and a forest will appear that can perpetuate itself indefinitely. Such an assemblage is called a **climax association.** It is the highest type of vegetation which the climate of any region will support.

In the succession we have just traced, the lichens were xerophytes and the species of the climax forest were mesophytes. Such a succession, from a xerophytic to a mesophytic level, is known as a **xerarch succession.** Observing the filling in of a pond or lake, we can see a succession beginning with algae found in the water and running through bulrushes—cattails—sedges and grasses —alders—swamp forest—to climax forest. Such a succession, which has gone from a hydrophytic to a mesophytic level, is called a **hydrarch succession.** All successions, regardless of their origin, progress toward the climax association. Of course, retrogression may set in at any point owing to an invasion of fire or some devastating disease, such as the chestnut blight.

Likewise it can be demonstrated that any change in the nature of the vegetational cover is accompanied by a corresponding change in the nature of the animal community. In other words, we have animal succession as well as plant succession. In the filling in of a pond we may observe an interesting succession of animal life. When the pond was young, the water was comparatively free from stagnation. Bass and pickerel thrived there. As the filling in continued, these species of fish were gradually replaced by carp, bullheads, and perch. The pond was likewise a breeding place for aquatic insects such as dragonflies and mosquitoes. When the pond has been succeeded by a swamp, all fishes have vanished. The aquatic fauna is now made up mostly of amphibians, such as frogs, salamanders, and certain species of snakes. Mosquitoes continue to breed in the open pools. With the final filling in and complete elimination of the swamp, the meadow or swamp forest develops in which we find the animals of the meadow or forest floor, such as meadow mice, moles, rabbits, skunks, and various non-aquatic insects.

However, with respect to succession, there is one very fundamental difference between plants and animals—the plant is sessile and the animal is mobile. If conditions become unfavorable the plant dies, but the animal may move out and on. The plant has some measure of mobility in its seeds, spores, and other propagules, but nevertheless it is more restricted than the animal. The migrations of the animal are limited by its capacity for adjustment; yet they are sufficient to render the animal community more readily modifiable than the plant community.

For convenience and greater simplicity we have discussed plant and animal communities separately, but it should be emphasized again that they are component parts of a basic unit, the biome. Vegetation and animal life are interacting phases of one dynamic complex.

Layer societies. The habitat of the biome may be subdivided into smaller habitats corresponding to the different divisions of the climax

FIG. 319. Layer societies. Three levels are clearly shown: the herb layer, the higher shrub layer, and the trees. *Photograph by Stanley Cain.*

stages. Then there are the habitats of each individual organism, as has been indicated previously. The occurrence of different groups of organisms in different levels of the habitat necessitates the recognition of layer habitats, each one occupied by a specific grouping of plants and animals called a **layer society** (Fig. 319). The upper layer or story of foliage comprises the leaves of the trees and lianas. The next story below is represented by smaller trees such as redbud, dogwood, or other species that require less light. Beneath them is a third layer or story consisting of the low shrubs and herbaceous plants commonly found in the forest. Finally, there is a ground-floor society of algae, fungi, mosses, liverworts, and other plants that can grow and thrive in very weak light. Although light is a dominant factor in the development of layer societies, decreased evapora-

tion, resulting from shading, doubtless plays an important role in the development.

We also find that characteristic animal life is associated with each of the different layer societies, as has been pointed out by Allee in respect to the tropical rain forest. The highest tree-top level is the abode of certain insects, birds, and other animals. Successive lower levels support their characteristic animals until we finally come to the forest floor, where the animal community is made up of ground dwellers like turtles, snakes, salamanders, and many other animals including such larger forms as the wild hog or peccary, and the tapir. Thus both animals and plants become organized into layer societies, and each of these communities contains its own peculiar group of organisms.

Seasonal societies. The adjustment of the life cycle to periodic changes in the habitat has resulted in a grouping of plants that sometimes is quite conspicuous. The so-called vernal plants, for example spring beauty and hepatica, spring up very quickly at the beginning of the growing season, produce their flowers, and mature their seeds or have them well started before the leaves of the trees have developed sufficiently to reduce the light. Extensive beds of spring beauty and fawn lily (*Erythronium*) illustrate such an adjustment to the vernal season, and a community of this sort is known as a **seasonal society.** Most of the vernal plants have bulbs, corms, tubers, rhizomes, or storage roots, and, during the brief period in which their photosynthetic machinery is operating, they store up food so that rapid growth is possible when the next growing season is ushered in.

In the development and structure of the biome, cycles of various kinds and degrees are of common occurrence, but their causes are not often fully comprehended. Fluctuations in population are often observed to occur, periods of abundance alternating with periods of greatly decreased numbers in a more or less definite cycle. In plants, with the exception of certain of the lower forms, such cycles are not so conspicuous as they are in animals. However, in their structures, such as growth rings, plants frequently show evidence of a rhythmic response corresponding with a similar cyclic alternation in environmental conditions. Even though there has been little quantitative study of animal cycles, they have long been a subject of great interest. Much evidence has accumulated in support of the theory that the probable primary cause of cyclic changes in both plants and animals is the sunspot cycle. The maximum and minimum occurrence of sunspots alternating through an average period of 11.2 years is thought to have a decided effect on the weather and all related biological phenomena.

CONSERVATION

In his numerous and varied coactions with other animals and plants, man is an ecological factor of first importance. Like all other animals, man obtains his food either directly or indirectly from plants. However, by reason of his superior intelligence he has learned to cultivate the plants, and to rear the animals he wants, thus exercising a large measure of control of his food supplies. In

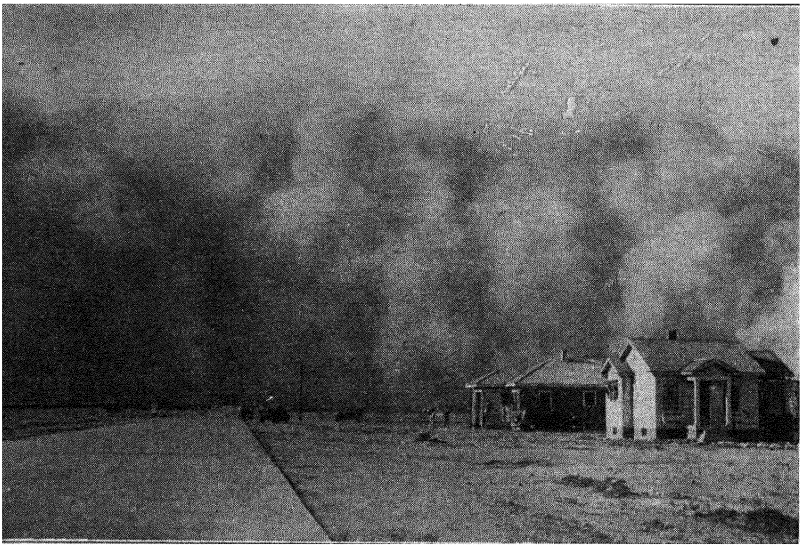


FIG. 320. Dust storm. *Photograph furnished by the Soil Conservation Service.*

pursuit of his personal interests, man has sidetracked the train of events occurring in a normal biotic succession and by so doing has unwittingly facilitated the work of destructive agents. By plowing up the soil he has destroyed the natural vegetational cover and exposed the soil to the erosive forces of both wind and water (Fig. 320). We are told that on May 12, 1934, one dust storm removed 300,000,000 tons of fertile topsoil from the Great Plains country, and that, annually, wind and water combined carry away and render useless 3,000,000,000 tons of soil. To clear the land for cultivation, man cut down the forests. The trees not needed to furnish construction material for immediate use were burned. To obtain yet more land for cultivation man has drained marshes, ponds, and even lakes. By all these activities he has upset the dynamic balance of factors operating in natural succession. Only comparatively recently have

we become sufficiently aroused to some appreciation of the impending disaster that must ensue if these destructive practices are continued. We are beginning to realize that destructive coactions must be replaced by constructive coactions in an attempt to restore a dynamic balance within plant and animal communities. In other words, we are now beginning to practice **conservation** (Fig. 321).

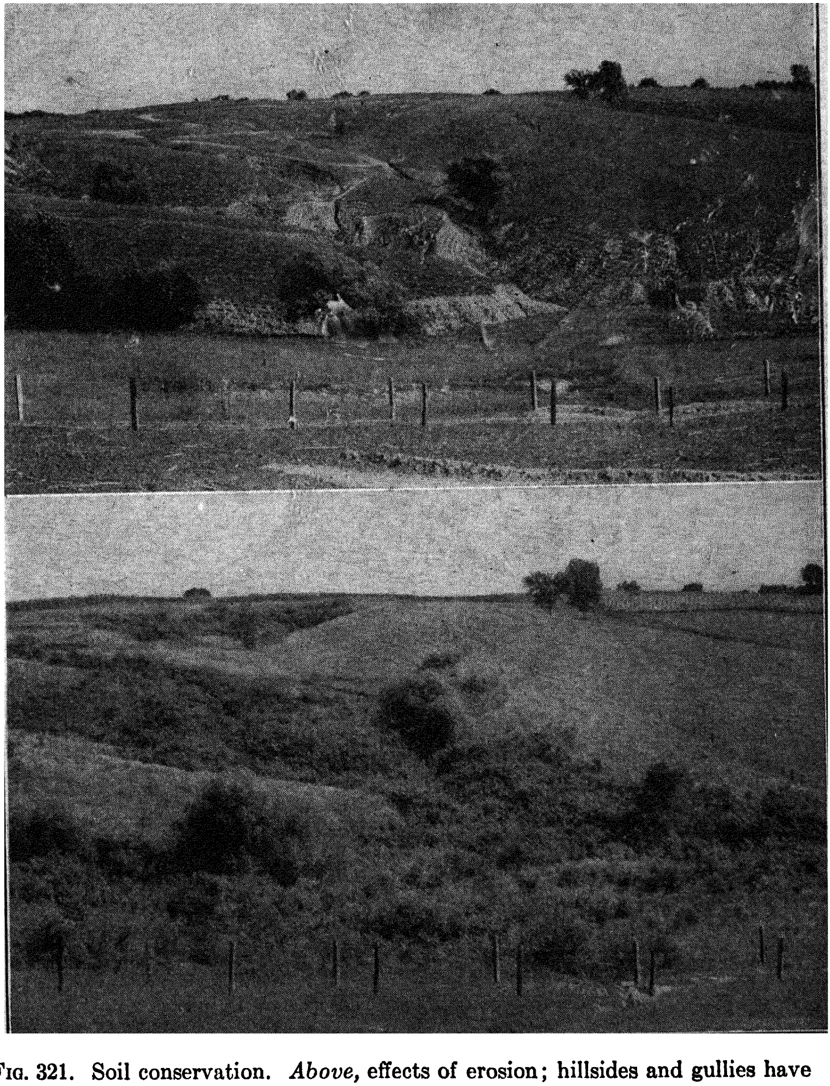


FIG. 321. Soil conservation. *Above,* effects of erosion; hillsides and gullies have just been planted with black locust and ash seedlings. *Below,* same area after two years have passed. *Photographs furnished by the Soil Conservation Service.*

Soil conservation. Since all animal life depends upon plant life, and plant life, in turn, depends upon the soil, the first and basic need is the conservation of the soil. Fertile soil is a very complex organization of mineral substances, air, water, and living organisms. The

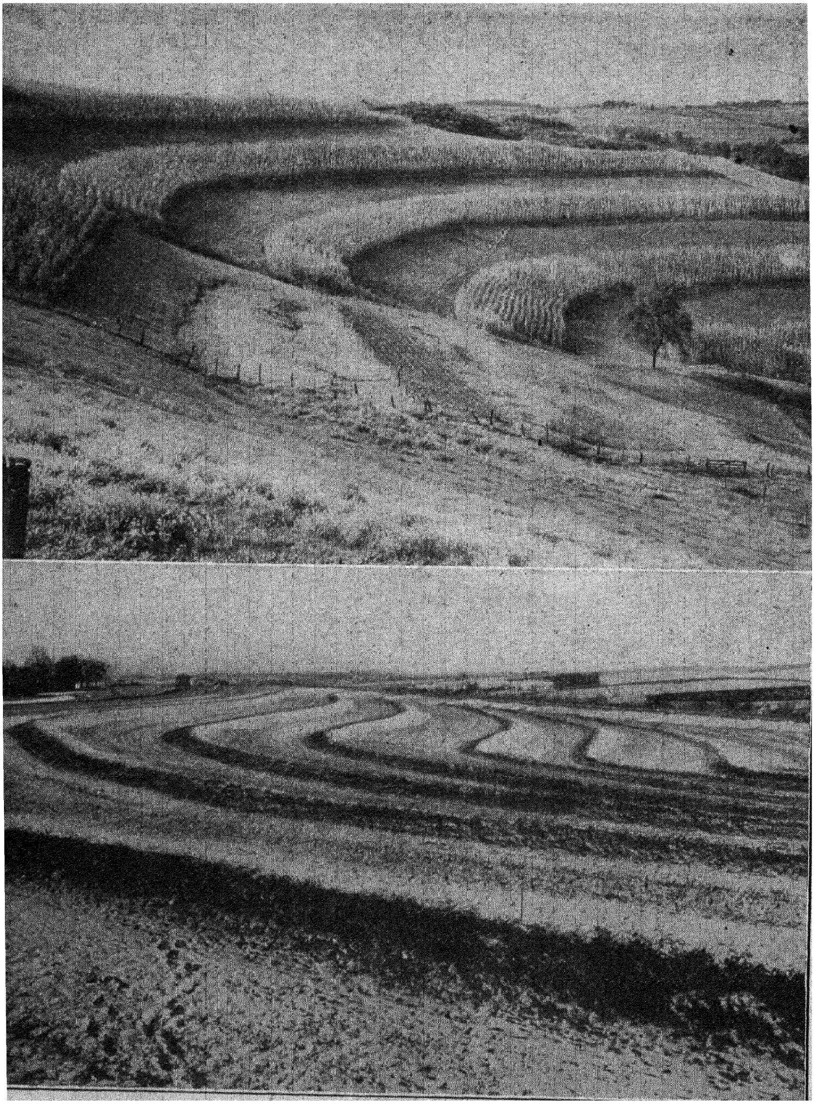


FIG. 322. Conservation. *Above,* conservation of top soil by strip cropping; *below,* water conservation by terracing. *Photographs furnished by the Soil Conservation Service.*

building of such a soil requires long periods of time, but it can be disorganized or removed by erosive action in a comparatively short time. The best way to conserve the soil is to maintain a vegetational covering. In cultivated fields various conservation methods are employed, depending upon the slope, nature of the soil, rainfall intensity, and other factors. Contour plowing and strip planting are necessary on relatively steep slopes (Fig. 322). Where active erosion must be checked, terraces are built usually in combination with spillways, check dams, floodways, reservoirs, and the like. If erosion can be checked sufficiently to permit the development of a close plant cover, stabilization will occur, and normal succession can be maintained.

Flood control. The second prime need is the conservation of water. Obviously the measures required to conserve soil are equally effective in the conservation of water. Instead of ditching and draining to hasten the flow of water from the land into the rivers and the sea, every effort should be made to obtain the largest possible utilization of water before it finds its way to the ocean. Natural marshes, ponds, and lakes, previously drained, should be restored. As much water as possible should be retained near the place of precipitation. Dams and reservoirs may have to be built, but their cost will be eclipsed by the saving effected in the consequent prevention of floods. A ground covering of plants is one of the most effective agents of water conservation; forest cover is especially effective, for the floor of duff and leaf mold serves as a great sponge to absorb and retain the water.

Forestry. Man's use and misuse of the forest have given rise to many serious problems. When the first settlements were made in the United States, approximately 820,000,000 acres, or slightly less than one-half of the total acreage, was occupied by forest. Today, only a small remnant of this vast forest is left. By his wasteful "cut-and-get-out" system man all but completely destroyed the forest, and now he is told that at least 630,000,000 acres, or slightly less than four-fifths of the land originally covered by forests, would prove more valuable in forest production than it can be when used for any other purpose. As mentioned previously, the forest is an all-important factor in soil-building and in regulation of stream flow, thus helping to control erosive activity. The forest provides shelter and food for many different wild animals, grazing for domestic animals, and much useful material and recreation for man. Realizing more clearly the large importance of the forest, the people of today are becoming more interested in forest conservation. In contrast to the greedy attitude of those who exploited the forest because of the

great value of the lumber produced, many people now consider the services rendered by the living forest more valuable than the timber itself. Recreation has become a major forest land use in the national forests.

In 1916, approximately 3,000,000 persons visited the national forests, and since that time the number of visitors has increased more than tenfold.

Modern forest management observes two basic principles, viz., **multiple use** and **sustained yield harvesting.** The first of these principles implies that all possible uses of the forest are taken into consideration and that the greatest use to the greatest number of people will be insured. Near some large city the forest might prove more useful as a watershed protection directly affecting the water supply. A subordinate use would be for recreation during some part of, or throughout, the year. The second fundamental principle of modern forestry practice aims to provide for continuous annual cropping, or what is generally called a sustained yield. A sustained yield is obtained when new timber is being produced as rapidly as timber is being removed by cutting, fire, and all other causes. The oncoming crop of new timber must be produced in such quantity that dependent industries and dependent labor can be kept active continuously. Under the old system of exploitation, after the timber was cut, the men moved on to some new location, leaving behind devastated country, ghost towns, and bankrupt communities. The sustained-yield plan provides for steady, continuous employment and income and thus for the stabilization of the communities that develop in the vicinity of the mills. Forest management requires the direction of trained foresters under whose supervision a varied program is carried on. Some of the activities involved are: fire prevention, protection against forest insects and diseases, the regulation of cutting, artificial reforestation of severely burned areas, and improvement of timber stand.

Wildlife conservation. The forest has always been known as a natural home of wildlife. Here we find moose, elk, and deer; bear, bobcat, wolf, and mountain lion; wild turkey, ruffed grouse, and mountain quail; beaver, racoon, marten, and wolverine; and many smaller forms including both birds and mammals. The destruction of the forest has changed the picture. After the removal of its natural cover and deprived of its natural food supply, much of our wild animal life has vanished. The passenger pigeon is extinct, and the wild turkey has become rare in most sections of the country. Killing by the hunter has been a factor in the reduction of wildlife, but undoubtedly the disturbance of natural conditions has been a more influential agency. Within recent years a lively popular interest has developed in wildlife conservation. One of the most-publicized examples of this interest has been the program of conserving deer. Originally, it was believed that, if refuges were established, the deer would multiply and establish themselves securely. The experience

with deer in Pennsylvania and the Kaibab herd taught the conservationists that under protection and provided with favorable conditions deer will multiply until overpopulation results and starvation ensues. On the Kaibab National Forest the deer population became so large that the territory was severely overgrazed. Many of the better browse plants were actually killed, and with the resultant food shortage the continued existence of the entire herd was imperiled. Many

FIG. 323. The last heath hen—a now-vanished species of bird, once very abundant. *Photograph furnished by the Fish and Wildlife Service, U. S. Department of the Interior.*

other examples could be cited, but this will serve to illustrate the need of wildlife management, a modern conservation measure that attempts to make use of available ecological and biological information in the solution of urgent wildlife problems.

One of the many problems confronting the wildlife manager is the control of predators. The numerous so-called vermin campaigns being waged in all parts of the country give evidence of the wide popular interest in this problem. The subject is one of great complexity, the ramifications including matters of economic welfare as well as the natural balance of animal populations and the interests of sportsmen. Many of the control measures now in vogue are based on too much positive opinion unsupported by sufficient knowledge. Many of the vermin campaigns, as one author says, "are a waste not only of time and effort but also of an element of the native fauna." Wise measures of predator

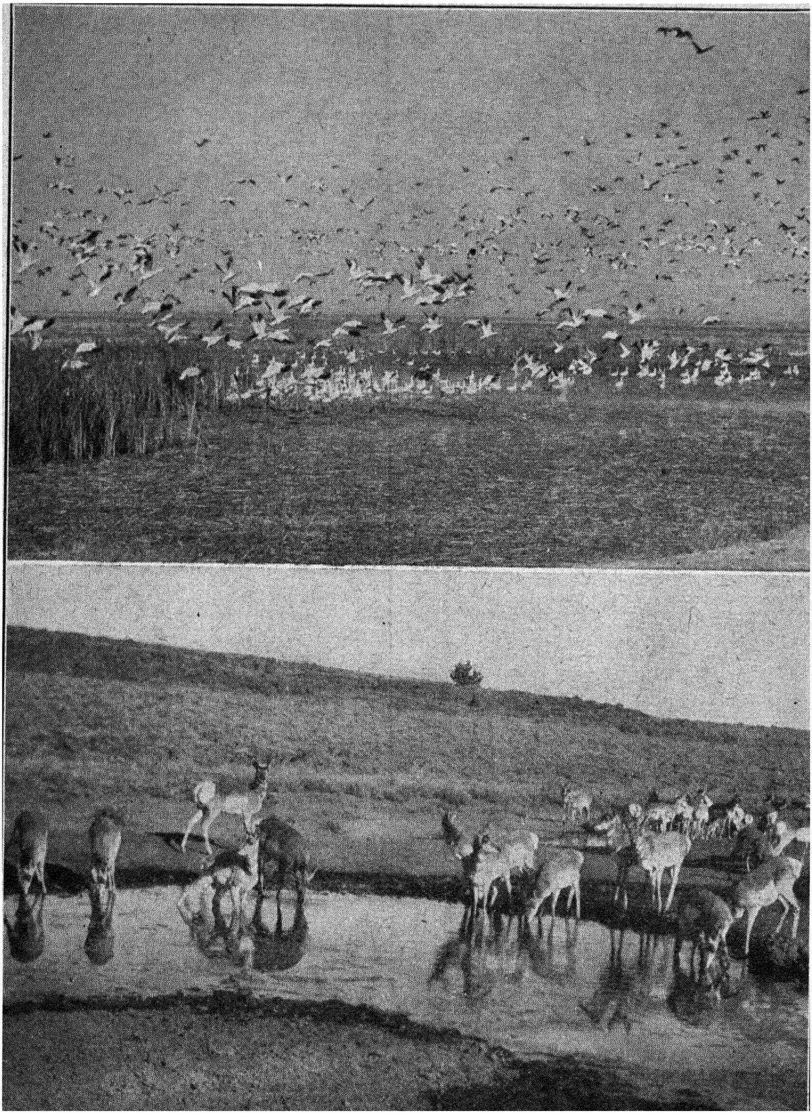


FIG. 324. Wildlife refuges. *Photographs furnished by the Fish and Wildlife Service, U. S. Department of the Interior. Upper photograph by Van Huizen; lower by Greenwalt.*

control demand intensive study of each particular problem in each separate community, for, in each instance, coactions are involved whose ultimate influence cannot be ascertained by mere guessing.

MIGRATION

We have already spoken of the migration of animals in relation to changes in plant communities, but there are other migrations, more or less rhythmical in nature. Some of them are rather erratic, some are seasonal, and others take place only once or twice during the life of the individual. Although several theories have been proposed to explain the cause of such migrations and how the habit began, the question still remains unanswered. Salmon live from two to seven years in the ocean and then, fasting and living on stored fat, they migrate up the rivers in great numbers, struggling through rapids and leaping water falls, until the come to the headwaters, where they spawn. As a result of their journey, the fish become flabby and frail and many soon die. After remaining in the fresh water six to eighteen months, the young fish move down to the ocean. Eels, on the other hand, live in the fresh water for a number of years until they become sexually mature. Then they migrate down the streams to the ocean where the eggs are laid, after which the old eels apparently die. After living for a time in the ocean, the young eels migrate into the fresh water of the rivers.

The annual migration of birds is one of the most puzzling problems of animal ecology. The practice of bird banding has taught us many facts concerning the phenomenon. For example, it is now known that many birds after making a long migratory flight will return the next season to the same place whence they started.

Dr. Allen tells a story about three tree sparrows that he trapped and banded in January. In March, they left for their nesting grounds in the north. In January of the following year, three tree sparrows visited his feeding shelf, and when they were trapped he found that they were wearing the bands which he had placed on them the preceding January. A similar experiment has demonstrated that a chimney swift, after spending the winter in the southern part of North America, returned the following spring to the same chimney it had occupied the year before.

What guides these birds back to their old homes after making such long journeys to distant places? Numerous answers have been given to this puzzling question. For a long time it was thought that birds possessed some innate sense of direction, but more recently, through extensive experimentation, evidence has accumulated that seems to

indicate the role of perception and memory in guiding birds over their migration routes. This may be the final verdict for migrating adult birds but it does not seem to explain the behavior of the young birds migrating for the first time. Such juvenile birds may be guided by older birds that chance to be in the same migrating flock. More evidence is necessary to give a final answer to this phase of the problem. Physiological adjustments at one time might cause the bird to move in the direction of warmer latitudes and at another time toward cooler regions. Further investigations are needed to give more definite and accurate information concerning all phases of this most interesting problem.

The eastern golden plover summers on the shores of the Arctic Ocean and winters in South America (Fig. 325). Every autumn the Pacific golden plover flies from Alaska to the Hawaiian Islands, and since his route lies over the Pacific Ocean he is compelled to travel the distance of 2,000 miles in one single non-stop flight. But, as far as long-distance flying is concerned, the "ace" of all birds is the Arctic tern. This bird may celebrate the Fourth of July in Greenland or Labrador but always enjoys Christmas somewhere south of the Antarctic Circle, requiring a tour of 11,000 miles. If this bird returns to the north the next season, the total distance covered in a single year will be not less than 22,000 miles.

As a usual thing, birds migrate mostly at night and advance rather leisurely during the day. The robin averages about 13 miles a day in going from Louisiana to Minnesota, increasing its speed with increasing latitude, until it covers 31 miles a day in southern Canada and 52 miles a day in central Canada. By the time it reaches Alaska it advances 70 miles a day. The speed of flight of the different birds varies considerably. The homing pigeon during a period of 4 hours averaged 55 miles per hour. The speed of the blue heron is about 35 miles per hour; migrating geese approximate 44 miles per hour. Studies reported by the U. S. Fish and Wildlife Service show that the duck hawk can travel from 165 to 180 miles per hour. Among wild ducks, the canvasback is about the fastest—72 miles per hour. Smaller birds fly at a somewhat lower rate of speed, varying from 20 to 35 miles per hour.

In addition to these more or less regular rhythmical migrations, there are others of a sporadic nature, such as the flights of butterflies, locusts, dragonflies, and other insects. They have been explained as irregular, dispersal movements. At times, similar dispersal movements of other animals occur, such as the spreading of lemmings and squirrels. Thorough studies have been made of the periodical migrations of the lemmings, which are small ratlike rodents of northern latitudes. At times they reproduce in prodigious numbers and then great hordes of them migrate, chiefly at night, into the lowland regions. They move steadily forward, swimming streams, climbing walls, and overcoming all obstacles, although many are killed every

day. The march continues until they reach the sea, into which they plunge and continue on their course until they are drowned. Early settlers in South Africa tell of periodic southern migrations of hundreds of thousands of springbok, continuing day after day for some

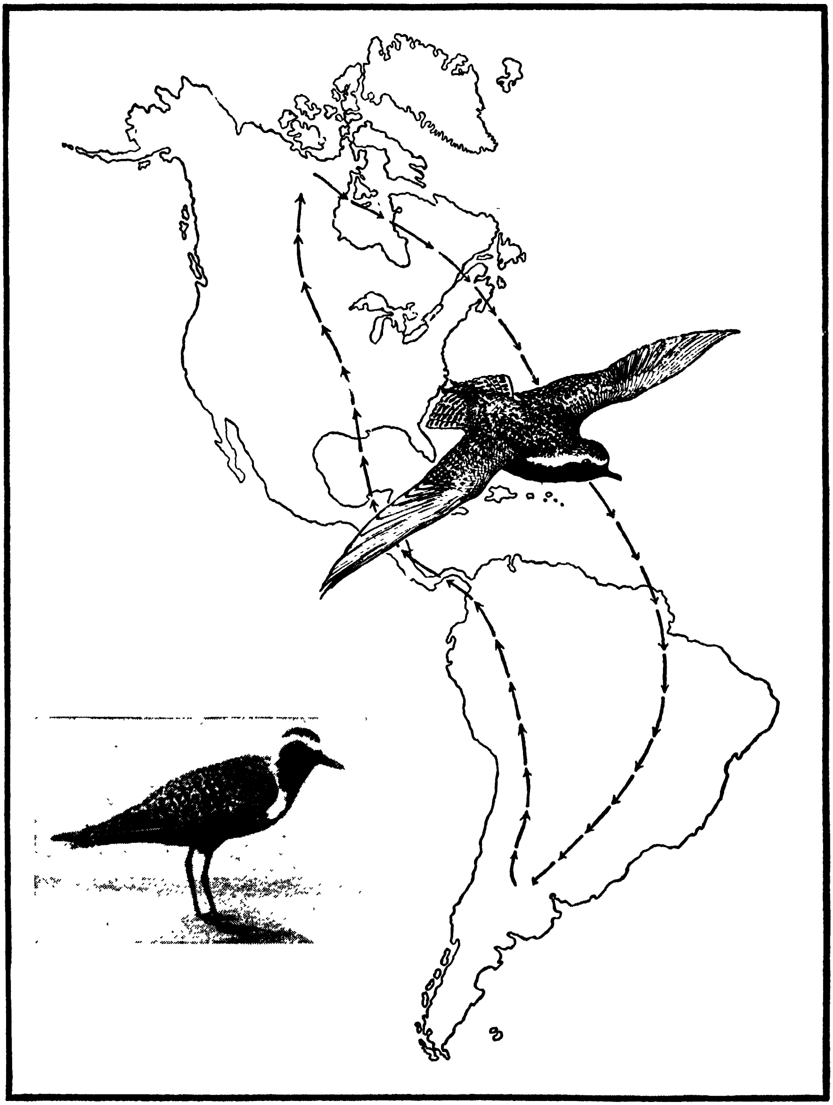


Fig. 325. The golden plover and route followed in its migration. This bird nests within the Arctic Circle in North America and spends the winter in Patagonia, South America. Arrows indicate the route followed. *Drawing by George M. Sutton. Photograph furnished by American Museum of Natural History.*

time. It is estimated that one of these great migrating hordes was 15 miles wide and 42 miles long—630 square miles of animals! The animals move steadily forward to certain death. It is difficult to see any advantage in such migratory movements as these.

ANIMAL AGGREGATIONS

Among the various animal and plant communities previously described, there often occur more or less numerous collections of animals which make up a unit or units within the larger communities. They are known as animal **aggregations.** From the social stand-

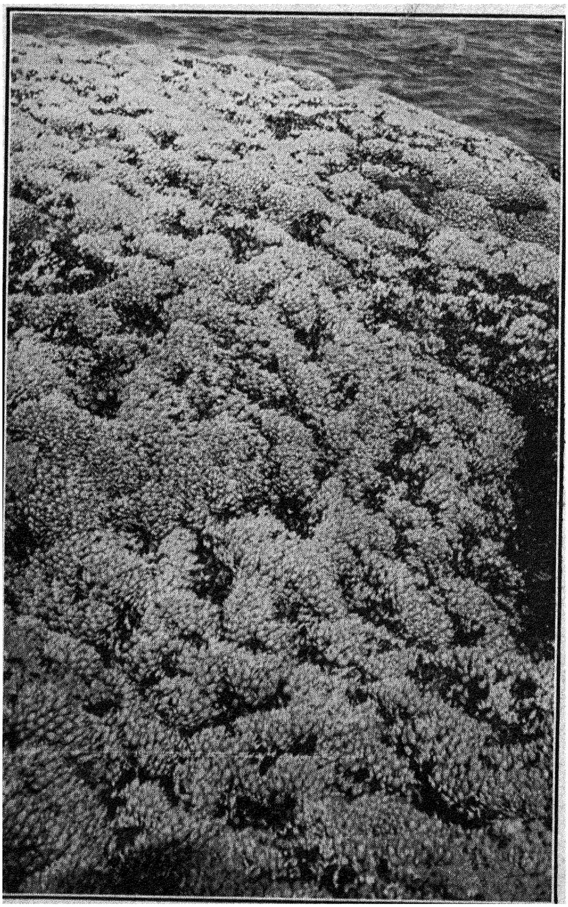


FIG. 326. Animal aggregation of goose barnacles (*Lepas*) and black mussels (*Mytilus californicus*) on the coast of Washington around mid-tide. *Photograph by Lynds Jones. Furnished by W. C. Allee.*

point they are often very loosely organized, but in the colonies of ants and bees they are closely knit into compact societies. These aggregations may be a result of some of the same factors that influence the formation of the larger communities, but here the animals themselves rather than the surrounding environment become the principal formation factor. The number of individuals which make up an aggregation varies. Some mound-building ants have as many as 10,000 individuals in the colony, whereas certain colonies

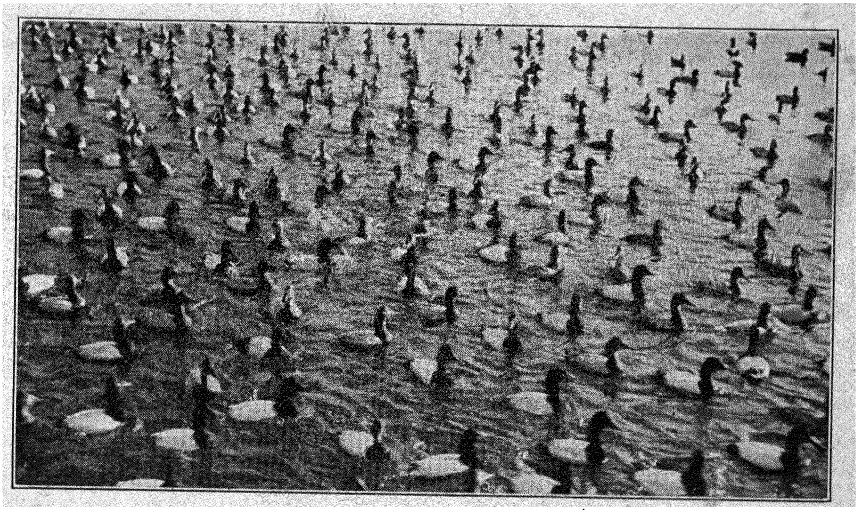


FIG. 327. Aggregation of canvasback ducks. *Photographs furnished by Fish and Wildlife Service, U. S. Department of the Interior. Photograph by Worcester.*

of tropical termites may contain as many as 3,000,000 individuals exclusive of other animal species which may be present.

Origin of aggregations. Sometimes animal aggregations may be the result of chance. Individuals driven ashore along the ocean beaches by the wind and tides may form groups living among the driftwood and debris. However, in most instances they seem to be brought together by reactions to such stimuli as light, heat, food, and moisture. Or the aggregation may be the result of inborn coactions of the animals to each other (Fig. 327). Thus we find certain insects which tend to collect near lights, and certain larvas of marine worms which aggregate in the regions of the most intense light. These reactions are apparently tropistic. Among certain animals, such as sowbugs or land isopods, one animal in its aimless wanderings comes to rest on a spot where there is more moisture. Here it will stop and other isopods will find the same place, and soon quite a

colony or aggregation forms. Or one isopod finding another may stop. These form the nucleus of a new aggregation which increases in number as other isopods add themselves to the group.

A species of the fresh-water catfishes forms a most interesting aggregation of this type. These animals, hatching from eggs in a nest, grow to form a school. Experimental studies show that they tend to move toward anything of similar form, size, and color. When two animals approach, they move their sensitive barbels toward each other and apparently receive some peculiar chemical stimulus which they recognize. Sometimes it is a touch reaction. When two catfishes push against each other they remain together, but, if one of the fishes happens to be of another species, it moves away. Catfishes may accept into their aggregation others of the same species but from different nests, forming what is known as an **open society.**

For the most part ants and bees form **closed societies.** Membership in this kind of colony is determined by a contact-odor system. If an individual does not have the proper odor, it does not belong. When attempting to break into a new society, ants having the wrong odor are quite often killed.

Types of aggregations. Some aggregations are very loosely organized. One of these is an overwintering aggregation of snakes, large numbers of different species of which aggregate in places where there is greater heat. Another frequent type of aggregation occurs during the breeding season. Thus the ordinary, solitary animals, such as frogs and toads, collect in large numbers in every available pond. This type of aggregation is true of insects, birds, and other animals. Sometimes aggregation occurs during dry weather and thus the animals are able to conserve moisture.

Sometimes the approach of nightfall sets in motion reactions resulting in the sleep or overnight aggregation. As many as a thousand solitary wasps have been known to collect in certain localities each night over a period of two weeks. Locusts and butterflies have the same habit. Blackbirds, chimney swifts, robins, and crows may roost so closely together that they actually pile on top of one another.

Integration of aggregations. In most aggregations there is a certain amount of integration or group organization. In the aggregation itself some integration is brought about by contact stimuli. Thus the movement of one animal is transmitted to the next, and so on to the next, until the entire group is affected. Sometimes, instead of a touch or contact stimulus, a chemical stimulus passes from individual to individual. Sight and sound also play an important part in group integration, particularly in birds and insects. Thus among crows a warning from the sentinel may set the entire flock in motion.

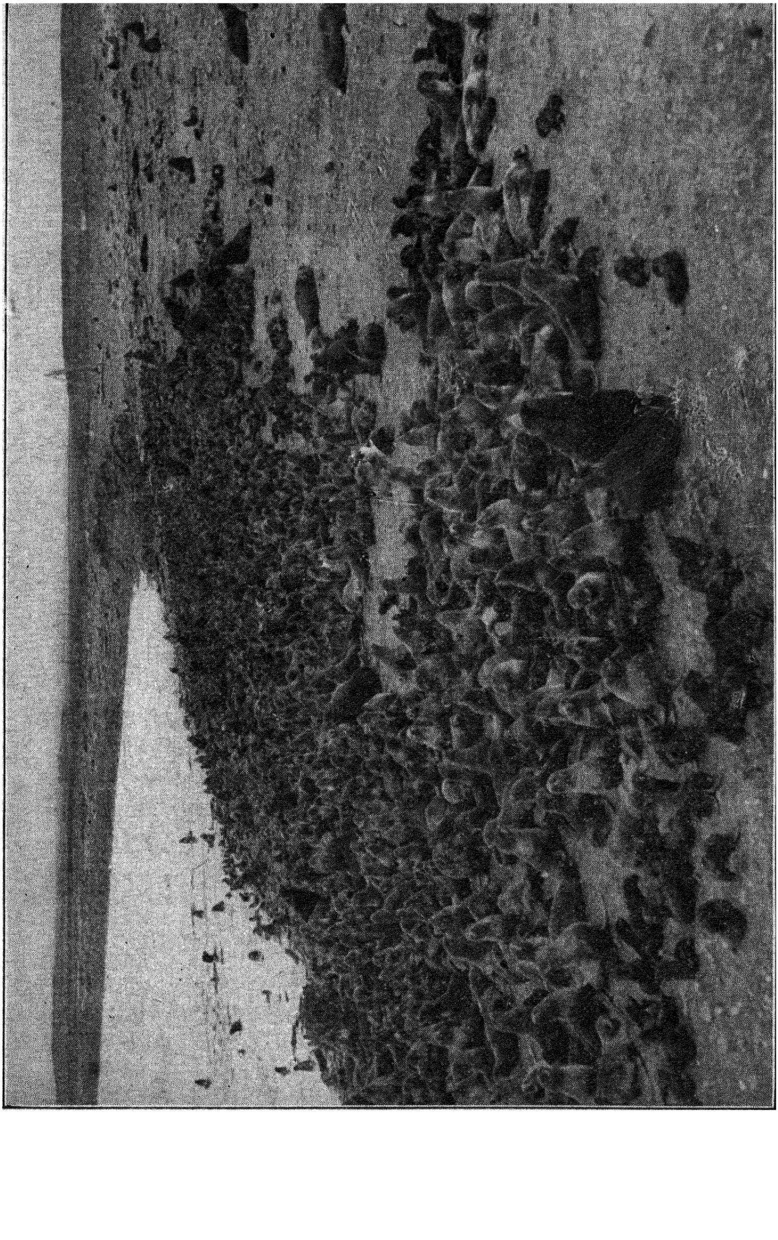


FIG. 328. Rookery of fur seals in aggregation. Note the large seals, bulls, surrounded by the smaller cows of the harem. *Photograph by Fish and Wildlife Service, U. S. Department of the Interior. Photograph by Carr.*

In a flock of chickens the "social" rank of a hen will be indicated by her reaction when another hen pecks her. Certain hens submit to pecking by other hens which apparently have the "peck right" over them. There apparently exists a "peck order" in which certain hens may peck others without being pecked in return. Rank in this "peck order" is established by fighting or by passive submission. Thus in a flock peck order may exist somewhat as follows: hen A pecks hen B; hen B pecks hen C; and so on through the flock. In a flock of hens, the cock leads the peck order!

Benefits of aggregations. It can be clearly seen that aggregation for breeding purposes has a very important role in the continuance of the race. Other effects of aggregation have been noticed. Attention has often been called to the stunted animals and the lowering of reproductive activities which result from dense aggregation. Moreover, under crowded conditions, the animals seemed to have a higher death rate. However, the work of recent years demonstrates that, in a given habitat, a large number of animals frequently have a better chance to survive than a small number. One of the effects of crowding is a lowering of oxygen consumption. As Allee expresses it, "The group exercises some sort of soothing effect upon the members that compose it." For certain aquatic species, apparently, the water of the environment must be conditioned by the animals living in it before it presents an optimum habitat for the group. The individual evidently gives off substances that tend to neutralize toxic materials in the environment. This is true not only of animals of the same species but also of animals of different species. Thus the fresh-water mussels excrete into the water certain substances that will protect fishes and other animals from various toxic substances. Indeed, many fishes, particularly aquarium fishes, thrive best in apparently stagnant water. Recent experiments have shown that fruit-flies will grow to a larger size under crowded conditions than when comparatively few are present. Experiments with various Protozoa and other animals show that the rate of reproduction is increased under crowded conditions. Out of these various aggregations, with the integrating factors and protective effects for the individuals and the race, may come the beginnings of animal social organization, which culminates in man.

Social life of some insects. Honeybees, ants, termites, social wasps, and other insects lead a communal life. The termites, or "white ants," are very primitive insects anatomically but have an elaborate social organization equaling that of the true ants, bees, and other Hymenoptera. Some of the termite colonies may num-

ber hundreds of thousands of individuals living in earthen or wooden nests. The material is chewed, mixed with saliva, and built into a nest that is as hard as cement. Some of these nests may be eighteen to twenty feet high. Usually the royal chamber is in the center, with other rooms and passages surrounding it. All are carefully protected from light and heat.

In the termite society we may find as many as eight castes with both males and females in each caste (Fig. 252). They may be summarized as follows:

1. First-form adults which are usually kings and queens. The royal pair lose their wings after they have taken a dispersion flight and settle down to form the colony. The queen is well fed, and her abdomen may increase to 20,000 times the volume of that of a worker.
2. Second-form adults are the substitute kings and queens—crown princes and princesses. They may take the place of the king and queen if these die.
3. Third-form adults are substitutes also for the royal family.
4. Workers without wings and possessing a small brain.
5. Soldiers without wings and with a very small brain. The jaws are so large and specialized that this caste must be fed by the workers. There are three castes of the soldiers.

Termites feed on dead wood and vegetable matter, which they are able to digest with the assistance of commensal protozoans living in their alimentary tract, another example of coaction. Termites have developed quite an elaborate system of mutual feeding called **trophallaxis.** They may feed each other on saliva, on "recalled" partially digested food, or even with fecal material. Some may even give off a fatty substance from the body which is licked off by fellow colonists. Logically, the queen gives off the most delicious and plentiful supply, and her greedy subjects often tear off pieces of the "royal hide" to increase the flow. Wheeler says that the members of the termite colony may be said to be bound together by a circulating medium of glandular secretions, fatty exudates, and partly and wholly digested food, just as the cells of the body of a higher animal are bound together as a "syntrophic" (*syn*—together; *trophein*—to nourish) whole by means of the circulating blood. Certain termites, like some of the true ants, cultivate their fungus gardens underground. They also have captive flies and beetles which give off secretions and so are carefully watched and cared for by the worker termites. A similar type of communal life is carried on by many insects in the groups mentioned, and the social organization developed is quite remarkable.

SOME FOOD RELATIONSHIPS OF PLANTS AND ANIMALS

Symbiosis. Mutual symbiotic relationships are also quite common. A good example among plants may be seen in the lichens. Here the algal component manufactures food both for itself and for the fungus,

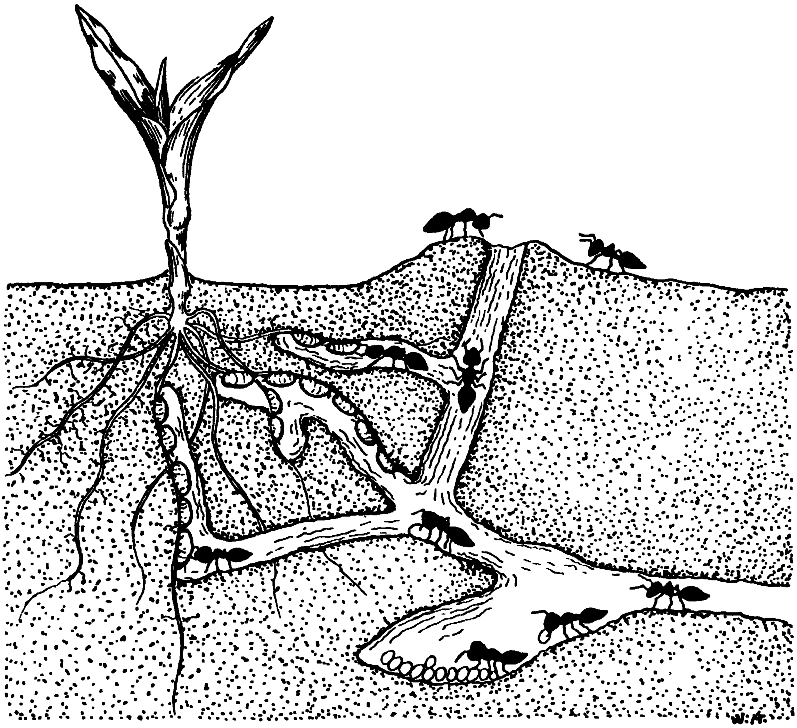


FIG. 329. Symbiosis of ants and aphids. The aphids are kept in the nests of the ants where they are cared for throughout the winter. In the spring the ants carry them through tunnels to the roots of corn plants, where they feed on the plant sap. In return the aphids give off a secretion that is relished greatly by the ants. *From Curtis and Guthrie, "Textbook of General Zoology."* (*After J. J. Davis, Farmers' Bulletin.*)

and the mycelium of the fungus invests the alga closely and protects it from desiccation. Thus the lichen can grow in extreme situations where neither the alga nor the fungus could grow alone. Another illustration of symbiosis often described is that of the ants and the aphids or plant lice. Certain species of ants carry aphids from one plant to another or even into their subterranean chambers, where they place them on the roots of plants. The aphids live on the juices

of plants so the ant has been of service in keeping them supplied with food. The aphids excrete a sweet liquid, often called "honeydew," of which the ants are very fond. They approach the aphids and, stroking them with their antennas, excite and cause them to excrete the honeydew. The ants eat these droplets of sweet liquid and are thus repaid for their service to the aphids, often spoken of as the ants' "cows" (Fig. 329).

Commensalism (*com*—together; *mensa*—table). Commensalism is a social relationship between two or more individuals of different species resulting in mutual benefit. A good example is furnished by the hermit crab and the hydroid colony. The crab lives in an old mollusk shell on which a colony of hydroids is growing. The body of the crab fills the shell, its head and large claws protruding from the opening. The hydroids have the advantage of eating the fragments of food left by the crab when it has finished its meal, and also the transportation furnished by the crab. On the other hand, the crab probably benefits largely from the protection afforded by the stinging cells of the hydroid.

Parasitism. Whenever one organism lives at the expense of another and confers no benefits in return, the relationship is called **parasitism.** The organism receiving benefit is the parasite; the other is the host. We have numerous illustrations in corn smut, wheat and apple rust, chestnut blight, Dutch elm disease, potato blight, dodder, plant lice, bedbugs, and tapeworms and roundworms discussed in Chapter XIII; many other parasites might be mentioned. Ichneumon flies have sharp ovipositors with which they puncture the wall of a cocoon or the skin of a larva of some other insect in which the female deposits her eggs. The eggs hatch quickly, and the ichneumon larvas attach themselves to the tissues of their host and devour it. When they have finished their meal the larvas emerge from the host and spin their cocoons. One may frequently see a caterpillar thickly studded with little ichneumon cocoons that will soon release a new crop of parasitic flies (Fig. 330).

One of the most interesting and helpful parasites is the *Megarhyssa* fly that parasitizes the larvas of the common wood-borer. The female pigeon horntail (*Tremex columba*) has a strong, sharp ovipositor by means of which she deposits her eggs at the depth of a half an inch in the solid wood of a tree trunk. The eggs hatch and grow into *Tremex* larvas—white, soft-bodied grubs that bore deeply into the trunk of the tree, forming extensive tunnels. A female *Megarhyssa,* finding one of these infested trees, guided by what mechanism no one knows, selects a spot directly over a *Tremex* tunnel and elevates her long, slender, flexible ovipositor over her back with its tip resting against the bark. Then, using her body as a derrick, she starts to drill a hole into the tree. When

her ovipositor penetrates the *Tremex* tunnel, she deposits an egg in it. Presently the egg hatches and the *Megarhyssa* larva creeps through the tunnel until it reaches its victim. It attaches itself to the *Tremex* larva, sucks its juices, and destroys it. When full grown, the *Megarhyssa* larva pupates in the burrow of its host and, when the adult form has developed, it gnaws its way out through the bark unless it is successful in following the *Tremex* tunnel to the outside.

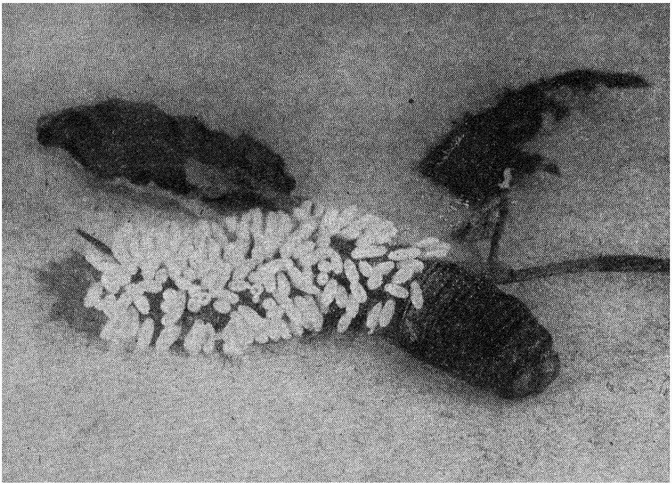


FIG. 330. Tomato worm covered with cocoons of a small Hymenoptera (*Braconid*) whose larvas are parasitic on the caterpillar. *Photograph furnished by the General Biological Supply House.*

There are all degrees of parasitism, from the merest beginnings of dependence to complete and obligate dependence. Poison ivy and woodbine depend on other plants for support only. The mistletoe has gone farther in its development of a habit of dependence on some host. It must procure its needed water and mineral salts from the tree on which it grows, although with this aid it can still manufacture the necessary carbohydrates. But such plant parasites as dodder, orobanche, and grain rust have become wholly dependent upon their hosts for all the food they need. Among animals we see similar degrees of relative dependence and completely obligate dependence. The burrowing owl, or "prairie-dog owl" as it is called in the west, will dig its own shelter if it cannot find one already available. However, it regularly uses the old burrows of prairie dogs, and this fact shows a shade of dependence creeping into the habits of this animal. All the barnacles in their sessile habit show a certain sug-

gestion of dependence, but the oft-described *Sacculina*, a parasitic barnacle that lives attached to the abdomen of a crab, represents the ultimate of dependence (Fig. 331). Its body looks like a swollen sac. It takes its nourishment from its host by means of threadlike structures that invade the tissues of the crab. It has reached the extreme limit of degeneracy, having lost its eyes, mouth parts, thoracic appendages, the segmented structure, and practically all semblance of a typical barnacle.

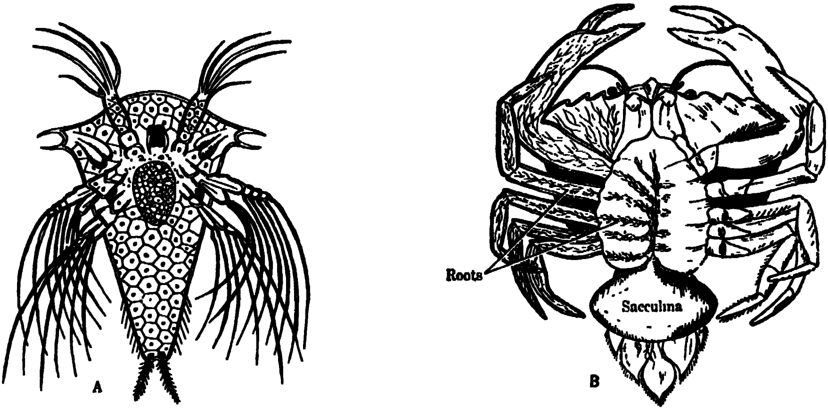


FIG. 331. *A*, crustacean parasite, *Sacculina*. *B*, the adult attached to the abdomen of a crab, and feeding on its host by means of "roots" which grow through the body. *Redrawn from Hegner, "Invertebrate Zoology."* (*After Leuckart.*) *By permission of the publisher, the Macmillan Co.*

SPECIAL PROTECTIVE FEATURES OF ANIMALS

Life for all organisms is a continual struggle for survival. The strong prey upon the weak, and these in turn prey upon those still less able to defend themselves. The following verse depicts this competitive interrelationship quite tersely and realistically:

Big fleas have little fleas
  Upon their backs to bite 'em;
And little fleas have lesser fleas
  And so ad infinitum.

In studying the struggle for survival we find various structural devices, form designs, and color patterns which may be of real assistance to both the hunter and the hunted, but are probably most helpful to the hunted. The turtle and armadillo are clad in a strong protective armor. The porcupine is amply protected by his quills against all comers except man. Elk, deer, moose, antelopes, cattle,

bison, and rams have horns or antlers of various types; and the giraffe, deer, and antelope have sharp, knifelike hoofs. The deer, antelope, rabbit, and many other animals depend largely upon fleetness of foot to escape the attacks of their enemies.

Protective coloration. It is a well-known fact that certain animals elude their foraging enemies by reason of their resemblance to immediate surroundings, or to other, more noxious or ferocious animals. There are birds whose plumage blends so closely with the background that we may pass within a few feet of them without seeing them. The arctic ptarmigan changes its plumage and the varying hares

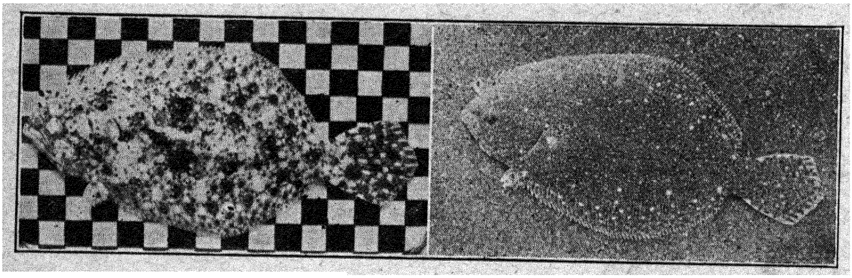


FIG. 332. Protective resemblance. Note the pattern of the flounder resting on two different backgrounds. *Photographs furnished by the Fish and Wildlife Service, U. S. Department of the Interior.*

change their pelage to match their surroundings. Their brown coats of summer are changed to white in winter so that they match well the snowy landscape. However, it must be observed that this same protective device may likewise help the snowy owl to capture the varying hares. The stripes of the zebra of Africa, browsing in the tall grass, may make it less conspicuous to its enemies, but a similar arrangement of stripes may assist the Asiatic tiger in stalking its prey. The chameleon and the flounder can readily change their own color pattern to match closely that of the substratum upon which they chance to be resting (Fig. 332). All such color patterns and color changes as have been mentioned are generally considered forms of protective coloration.

Special resemblance. In form, or by reason of some peculiar behavior or position, some animals may closely resemble certain inanimate objects in their environment. Thus the walking-stick looks like a dead twig. Some of the leaf hoppers resemble buds and young leaves. The classic example of this type of protection is the dead-leaf butterfly (*Kallima*) of India, whose folded wings closely resemble the leaves of the twig on which it may be resting (Fig. 333).

Mimicry. Another feature supposed to be of protective value is mimicry. In color and pattern, certain non-poisonous or less noxious insects may resemble poisonous or less palatable insects and thus escape capture. In this way the inedible monarch butterfly (*Anosia plexippus*) may be mimicked by the edible viceroy (*Basilarchia archippus*). The poisonous coral snake is closely mimicked by the

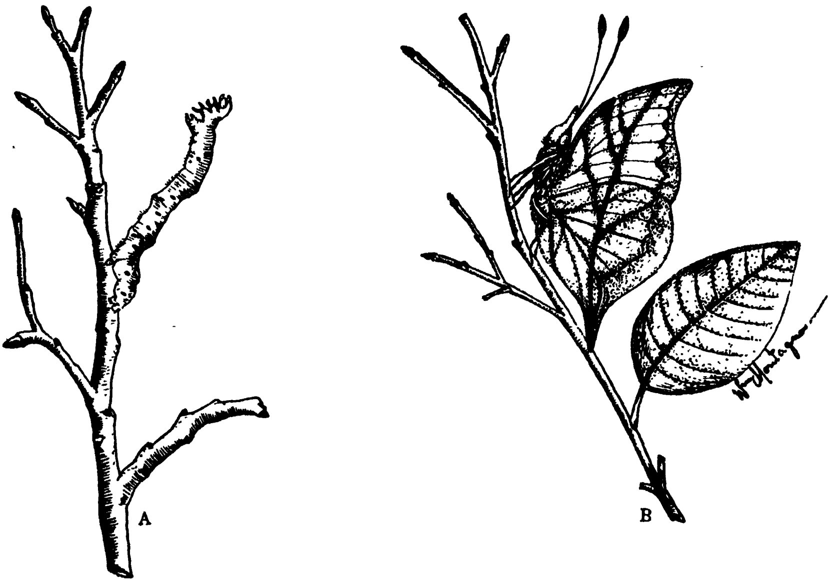


FIG. 333. Protective resemblance. *A*, resemblance between a geometrid larva and a twig. *B*, resemblance of the folded wings of the Indian butterfly, *Kallima*, to the leaves of a plant. *Redrawn from Heath, Jordan, and Kellogg, "Animal Studies." By permission of the publisher, D. Appleton-Century Co.*

harmless scarlet king snake. Other interesting examples of supposed mimicry might be cited.

Other special survival adjustments. Some animals may emit disagreeable odors, as the musk turtle, certain insects, and the much-maligned skunk. Death-feigning is practiced by certain animals, the opossum for example (Fig. 334). The harmless puff adder does a good job of bluffing with its hissing and ferocious demeanor, or failing in this it, too, may "play dead." Some animals are said to possess warning colors. Thus the white tail feathers shown by the meadow lark, junco, and other birds may serve as an alarm signal to others of their kind. This same function has been attributed to the "cottontail" of the rabbit and the white tails of certain species of deer.

Some poisonous snakes and stinging insects are rather brilliantly colored—supposedly a warning that they should be left alone and undisturbed.

Fig. 334. Opossum—death feigning ("playing possum"). *Photograph furnished by the Fish and Wildlife Service, U. S. Department of the Interior. Photograph by McColm.*

SUMMARY

The relationships between different organisms and those that obtain between organisms and their physical environment constitute the subject matter of ecology. Physical factors influence the organism, and by its reactions the organism produces changes in the environment. The combined factors that influence an organism in any way constitute its habitat. The organism is constantly struggling to maintain a favorable equilibrium with its own peculiar and ever-changing habitat. Living organisms do not exist separately and independently; they live in communities. A climax community is called a biome. In these communities organisms influence one another in various ways. The influences are called coactions. Because of the reactions and coactions of organisms, communities are constantly changing, the result being a succession of communities ending

in a climax stage in which relative equilibrium with the climatic environment has been attained. Perhaps the most disturbing coacter is man, and his coactions have violently disrupted the normal course of succession. Within recent time, man has recognized the bad results of some of his practices, and he is now setting up conservation measures to repair damages, as far as possible. The prime conservation interests are soil conservation, water conservation, and wildlife conservation. Among other interesting reactions and coactions of living organisms are migration, aggregation, integration, symbiosis, commensalism, and parasitism. There is also the controversial, probable development of protective structures, special resemblance that may give protection, and protective mimicry.

CHAPTER XVIII

WHAT IS EVOLUTION?

From the very earliest times men have been interested in the origin of living things and in how they came to be what they are. The idea of evolution is not so recent as many people think. The early Grecian philosophers thought about evolution and discussed it but failed to gather objective data. Anaximander (600 B.C.) was of the opinion that in the beginning there was a fluid earth which gradually dried up to give some patches of land onto which man, in fishlike form, crawled and gradually acquired limbs. Then came Empedocles (approximately 490–430 B.C.), who advanced a doctrine of strange creatures with mixed parts and wrong appendages, all of which later found their proper places to produce the modern forms of plants and animals. Aristotle (384–322 B.C.) later came much closer to modern ideas of creation, for he arranged the animals and plants in consecutive series, with the higher forms following the lower. Aristotle was a scientist. He based his conclusions on observations made on living plants and animals. Most of us are familiar with the interpretation of the account of creation in Genesis, how all species of plants and animals were created in the beginning, with the forms they now have. This explanation, called **special creation,** served as a satisfactory interpretation until about 1880. Even today, it satisfies those who have never troubled themselves to study the question objectively and scientifically. St. Augustine (?–604) and St. Thomas Aquinas (1125–?), leaders of the church, had thought that our present living forms came from a more primitive ancestry. However, it was not until the middle or latter part of the eighteenth century that man began to speculate once more concerning the mode of creation. About this time the French biologist Buffon, who was much interested in comparative anatomy, pointed out structural likenesses in animals and concluded that there must be blood relationship among them. He did not believe that the pig was a special creation, because he found two useless or vestigial toes in addition to the two functional ones on each foot, and he concluded that some ancestral hog had

used all four toes. But in later years he gave up the problem of origins as being impossible of solution.

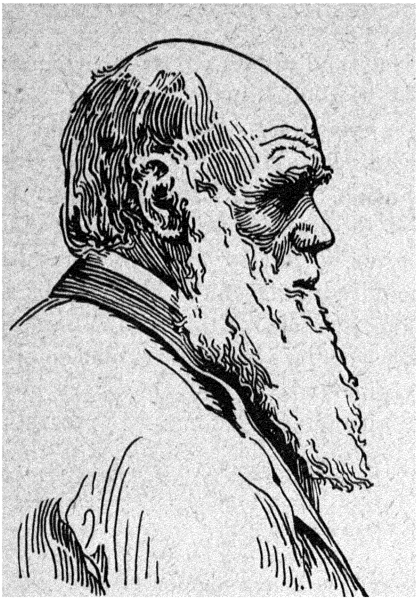
Lamarck pointed out that animals and plants vary with changing environmental conditions and that, as they adjust themselves to new conditions, they apparently change their form. He thought that this change within the organism was brought about by some inner drive toward a certain necessary adaptation. It was Lamarck's idea that organs *used* tend to develop and those *not used* tend to atrophy. The changes made or acquired by one generation could be passed on to the next. In other words, acquired characteristics could be inherited, a problem which we have previously discussed. Lamarck and his ideas as well as the whole general theory of evolution were opposed by Cuvier. There were others who held evolutionary ideas, but it remained for Charles Darwin, an Englishman, to present to the world the modern theory of evolution.

CHARLES DARWIN

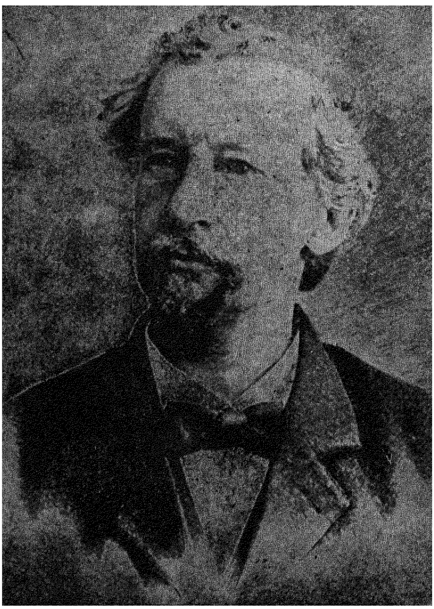
Today the mere mention of the theory of organic evolution at once suggests the name of Charles Darwin (Fig. 335). Darwin's father and grandfather were physicians. His maternal grandfather was Josiah Wedgwood, a careful, painstaking man who manufactured pottery which is famous even today. Thus we see that from the standpoint of both heredity and environment Darwin had a scientific background which may have strongly influenced his career. Darwin was a rather delicate boy and not a particularly good student. At his father's request he first tried the study of medicine, but sickened at the sight of operations. Then his discouraged family thought that he might make a minister of the church, but most of this study was neglected. He was graduated finally with no special honors. However, while at Cambridge he became acquainted with Henslow, a botany professor, and Sedgwick, a professor of geology, with whom he made many field trips. It was the influence of these men that initiated and helped to shape the future career of young Darwin.

Shortly after Darwin's graduation in 1831, Henslow arranged for his appointment as naturalist on the British ship *Beagle* which was soon to set sail on a mapping journey around the world. Darwin's father was opposed to this trip because he felt that his son should first do something about earning a living, and besides he did not think him fitted to do the work. However, he finally consented, and so Charles Darwin, aged twenty-two, started on what proved to be a five-year trip around the world.

Now among Darwin's reading material was Lyell's *Elements of Geology*, a new work just off the press, which Henslow, the donor, told him to read but not to believe. In his book Lyell advanced the thought that present-day geologic forces, such as earthquakes, volcanoes, and rain, could account for the earth's history and that the present geologic facts are the result of these forces operating in the past. Lyell concluded that this orderly geologic development was brought about by natural causes, but he thought that such factors did not operate in the organic world.

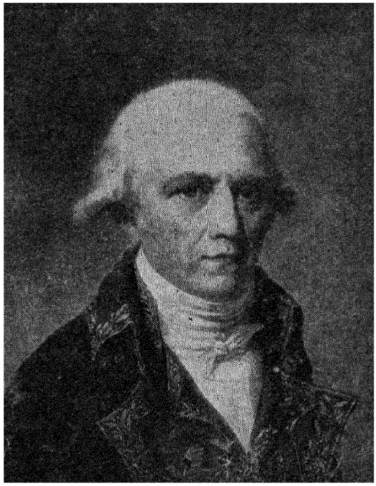


Charles Darwin (1809–1882). *By permission of Charles Schuchert.*



Hugo de Vries (1848–1935). *Photograph furnished by Henry Holt and Co.*

FIG. 335. Some early students of evolution.



Jean Baptiste Lamarck (1744-1829). *By permission of Charles Schuchert.*

FIG. 335—(*Continued*)

The *Beagle* with Darwin sailed on. In South America, Darwin was astonished at the multitude of plants and animals and was particularly interested in the sloths and armadillos. On some of his explorations ashore he found fossil skeletons of megatheriums and glyptodons which closely resembled living sloths and armadillos. He got the idea, therefore, that these fossils may have been the ancestors of the present-day sloths and armadillos. While studying the terracelike plateaus of Patagonia he found a series of marine shells resembling those of modern shellfish living in the sea. Later, while sailing along the west coast, he found the same geologic formation there as he had seen on the east coast, which suggested the possibility that both coasts of South America had been elevated from the bed of the ocean.

His ship made another stop at the Galapagos Islands. Here he found more similarities among the animals and plants of adjacent islands than among those of more widely separated islands. However, all the island forms resembled one another even more closely than they did those of the mainland. Therefore it seemed evident that the island forms were descendants of those of the mainland; but, widely separated from the homeland, they had gone slightly different ways. Darwin continued to study. He was interested in corals and studied coral island formation. He collected barnacles, in fact all kinds of animals and plants, which, with assistance, he later classified. He worked at the task of classification for eight years. Meantime he had written a narrative of the voyage and published a number of papers so that he had gained the respect of the world. However, the more he pored over his notes and the more he studied his material, the more thoroughly he was convinced that present-day forms are the descendants of former animals. Of this he was fairly certain, but how and why it happened he could not quite see. He once had read a book by Malthus on human populations, which pointed out that men would multiply more rapidly than the available food supply, if all of them lived. Moreover, Darwin had been impressed with the enormous overproduction of animals and plants. For example, if an annual plant produced

only two seeds, and all the seeds were to grow, there would be 16,777,216 in the twenty-fourth generation. It is estimated that the conger eel lays approximately 15,000,000 eggs in one season. Other plants and animals could be cited which are just as prodigious in their reproductive rates (page 289). It was quite clear that only a small percentage of animals and plants survived. Presumably, those which survived must have differed or varied somewhat, and in favorable ways, from those which perished. This last is natural selection, or the survival of the fittest, which we shall discuss in greater detail later.

Darwin finally wrote a full exposition of his ideas but when about ready to publish he received from Alfred Russel Wallace a manuscript presenting practically the same conclusions. Wallace asked Darwin to arrange for the publication of this paper, which Darwin generously decided to do rather than to publish his own, but finally both papers or essays were presented together. At once the conflict between science and theology became bitter and intense. The publication of Darwin's *Origin of Species* in 1859 served to fan the flames. Darwin won followers not only at home in England, but also in Germany and other countries, and today the idea of organic evolution is firmly fixed not only in the thinking of the scientist but also in that of the layman.

Although Darwin wrote many other scientific treatises besides his *Origin of Species*, he deserves special credit for collecting and presenting to the world such an accumulation of observations and data in support of the theory of organic evolution that it became widely accepted and still endures. In 1882, after a life of real service, Darwin died and was buried in Westminster Abbey where kings, statesmen, clergymen, artists, and other great men of England are entombed.

Darwin was in a peculiarly favorable situation to accumulate data and to formulate his theory of evolution. He had five years free from other distractions to study the flora and fauna of the world. Moreover, though his mind may have worked cautiously, he had wonderful perseverance and patience in the use of his remarkable powers of discrimination. It is to these characteristics of the man that we owe the first convincing statement of, and evidence for, the theory of evolution.

THE THEORY OF EVOLUTION

The theory of evolution holds that animals and plants, throughout the ages, have changed and transformed into new and different species. Indeed, such changes are responsible for the various present-day species of animals and plants, for the process of transformation is continually going on all about us like respiration, metabolism, and other physiological activities. However, it is moving so slowly that we cannot perceive it in the span of a lifetime. For instance, we cannot expect to see a cat develop batlike wings and fly. The keynote of this doctrine of evolution is the word *change*—a change in form from those organisms of the past to those of the present and a change from those of the present to those of the future. Nor do the changes necessarily imply development of "better" organisms, for

some plants and animals may degenerate whereas others increase in complexity.

It can readily be seen that the theory of organic evolution is vastly more dynamic in its concept than the older theory of special creation. Cuvier introduced a variation into the theory of special creation which he called **catastrophism.** According to Cuvier, great world-wide cataclysms occurred which completely wiped out the then existing plants and animals, after which new ones were created. For him, this explained the presence of the fossils very nicely.

Today, there is practically unanimous agreement as to the validity of the theory of organic evolution as a mode of creation. However, there is some diversity of opinion with respect to the mechanism of the process. Later in the chapter we shall see that Darwin had ideas concerning the mechanism, and collectively these ideas are today generally known as Darwinism.

Evidence for Organic Evolution

In the very beginning of this part of our discussion the reader is warned that a complete demonstration of the theory of evolution, such as we find in problems of geometry or chemistry, is impossible. Many difficulties and unsolved problems remain. Much of the evidence is indirect, and, though pointing to strong probabilities, it does not quite reach absolute certainty. The many varied and complex aspects of the problem, together with the slowness of the process and the countless millions of years involved, make the unveiling of the evidence very difficult. However, the fact that the lines of evidence seem to converge and lead to one common conclusion adds strength and probability to the proof of the theory.

Classification. We have already discussed Linnaeus and his system of classification of animals and plants. The fundamental unit or concept of this system was the **species.** According to Linnaeus, who believed in the doctrine of special creation, each species represented a separate act of creation and showed clear, distinct characteristics which separated it from other species. Moreover, each species had been here since the creation of the earth and was immutable. During his time and afterwards, the main task of the biologist was to ferret out the species, give them names, and place them properly in the classification scheme. In hunting down the "species," certain animals and plants were found that could be placed in their respective genera, but they differed so slightly from each other that one species graded into the next. In several recog-

nized genera of plants, for example hawthornes, asters, willows, goldenrods, and oaks, variable individuals frequently appear that cannot be assigned readily to any known species. Such plants possess characteristics common to two closely related species and thus represent intergrading forms, indicating that evolutionary change is taking place today in all living organisms. Controversies arose as to what constituted a species in these groups. For example, originally there was recognized only one species of giraffe, but today the one species is broken up into eleven subspecies. This intergradation between species is what we would expect according to the evolution theory which postulates gradual change on the part of the organism, but it certainly does not fit into a theory which assumes the creation of separate, unchanging entities. If we accept the evolutionary explanation for the creation of species, the relationships made evident by the groupings of animals and plants in the system of classification become more logical and natural to us and take on new significance. In fact, there is no known way to account for these similarities except on the principle of a common heritage.

Evidence from comparative anatomy. When we study and compare the structures found in various animals, several different plans of structure may be observed which may characterize certain great groups of animals. Thus we have already seen that vertebrates and invertebrates are more widely separated than fishes and birds, or than annelids and arthropods. Invertebrates possess a much greater variety of structural plan, and at first sight the structures found in the invertebrates of the various Linnean categories may not seem to be related. On the ventral side of the abdomen the crayfish has appendages called swimmerets, each made up of a basal piece joined to which are two other divisions. This is a **biramous** (two-branched) appendage which, with considerable variation, serves as a model for the walking legs, the claws, and most of the mouth parts of the crayfish (Fig. 237). Theoretically, the ancestor of the Crustacea may have been equipped with similar biramous appendages which became modified to serve various functions. Continuing the study of comparative invertebrate anatomy, we need only to call attention once more to the mouth parts of insects which have been modified to form chewing organs, long tubular structures for sucking as in the Lepidoptera, and the biting-sucking types found in mosquitoes (Fig. 241). Nor should we forget that the mantle of the mollusks may be modified as an organ to secrete a protective exoskeleton in the clam, to act as a breathing organ in certain snails, and as a locomotive structure in the squid.

If we select and compare certain structures, for example, the foreleg of the horse or cow, and the human hand, we cannot fail to note some similarity in general structural pattern. We have already seen that these structures are homologous, for they have the same embryological origin and general structure. Study of the muscles and nerves shows other marked resemblances. The human hand is a grasping organ with five nail-tipped digits, and it rotates on a flexible wrist with eight bones. The ulna and radius, as may be recalled, are two separate bones articulated with the humerus which fits onto the shoulder blade in a ball-and-socket joint. The human forearm and hand serve a multitude of purposes, whereas the horse uses the homologous structures for one purpose only—locomotion—which requires only a forward and backward movement in one plane. So in the horse we find only one big digit with its nail enlarged to form a hoof. Two other digits are present as rudimentary vestigial structures. The metacarpals are fused, and there are only seven wrist bones. The ulna and radius are fused into a single bone, and the joint arrangement is almost solely of the hinged type. Yet, in spite of these differences, we readily recognize the same fundamental plan of structure. If we compare the bat's wing to the organs just mentioned, we find the same pentadactyl plan of structure, except that here the bones are much elongated, especially the phalanges, and connected with one another by the wing membrane, which is attached also to the legs and the short tail. The digit corresponding to our thumb is free and tipped with a claw. In birds we find a great fusion of digits, carpals, and metacarpals, as well as some elongation of bones, particularly in the soaring birds. Here the function of the membrane of the bat's wing is taken over by feathers. Thus we might go on pointing out such similarities of structure in the vertebrates as variations and modifications adapted for burrowing, climbing, and swimming.

Comparative anatomy likewise supplies evidence in support of the evolution of plants. Structural studies of leaves, stems, roots, flowers, fruits, and seeds indicate clearly morphological resemblances and differences among the various groups of plants. Thus it is evident that roses, strawberries, blackberries, and raspberries are more closely related than potatoes, corn, beans, and lettuce. The greater the similarity of structure the closer the relationship, and, wherever close relationship is found, a common ancestry is indicated.

The testimony of comparative anatomy has been questioned because it does not connect such diverse animal types as crayfish and bony fishes, oysters and amphibians. It is hard to see much simi-

larity between a starfish and an oyster. However, we can find evidences of evolution among the shellfish themselves, and among the various echinoderms. And it is quite possible that thousands of intermediate forms may have lived and become extinct, of which we have no record at all.

Additional anatomical evidence is offered by what are known as vestigial organs, that is, structures which apparently are useless to

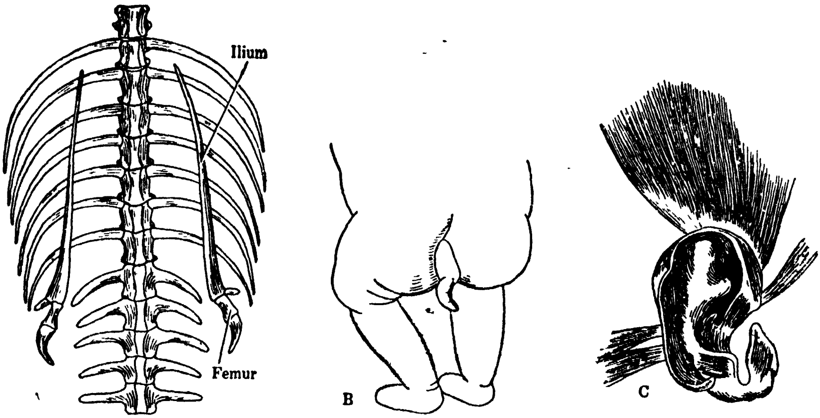


FIG. 336. Vestigial structures. *A*, vestigial hind limbs of the snake, *Python*. *B*, rudimentary tail on a newborn infant. *C*, vestigial and useless muscles for moving the human ear. *A and C redrawn from Romanes, "Darwin and After Darwin." By permission of the publisher, Open Court Publishing Co. B, redrawn from Arey, "Developmental Anatomy." By permission of the publisher, W. B. Saunders Co.*

an organism and not necessary for its existence. This phase of the discussion is well illustrated by the following analogy of Lydekker. If a screw-driven steamer has some of the machinery such as paddle boxes, paddle posts, and the like, all of which are used on a side-wheel paddle boat, two conclusions are possible—either the designer was crazy or the boat had been converted from the paddle type to the propeller or screw-driven type. Clearly the second conclusion is the only reasonable one. So, in the organic world, vestigial organs must be considered remnants of structures which were functional in ancestral animals.

The python has two claws, one on each side of the anus, and they are supported by slender bones. The claws are considered vestiges of hindlegs (Fig. 336). Further, many snakes have only one functional lung, the other lung being represented by a small budlike growth only. In many cave fishes and moles the eyes, although

present, are not functional. Whales have developed enormous tail flukes to drive them through the water, and, although the posterior limbs have apparently vanished, under the skin there are vestigial pelvic bones and other limb elements. A few more examples must suffice for this phase of our discussion. It has already been pointed out that in the foot of the horse there are two rudimentary bones which correspond in position to the second and fourth digits of the human hand. Perhaps the most interesting vestigial remnants in man are the groups of functionless ear muscles which correspond to those that serve to move the ears of horses and dogs (Fig. 336). The vermiform appendix is another vestigial organ. Then there are the Diptera, whose hind wings have disappeared except for the knobbed hairlike balancers. In some of the annelid worms, the larvas develop in cocoons from which they emerge as completely formed crawling "worms." Yet, in the close confinement of the cocoon, larval organs have been formed which would be useful only if the larvas were swimming in the water.

These are but a few examples of an imposing list of vestigial structures. Certainly it does not seem reasonable that these vestigial and often detrimental structures would have been developed if animals had had their origin by special creation. On the other hand, this is exactly what would be expected in an evolutionary process where the old is either constantly being worked over into something new or discarded altogether.

Evidence from embryology. We have already seen that embryology is the study of the origin and development of the individual from the egg to the adult. The different phases in the development of the individual organism are called collectively its **ontogeny** (*on*—being or individual; *genos*—descent). The study of the history of the development of the species or race is called **phylogeny** (*phylon*—race; *genos*). From the standpoint of evolution we are interested only in embryology as it throws light on the possible ancestry of the organism.

In the early part of the nineteenth century, many biologists, particularly students of embryology, placed much confidence in the theory that higher animals, in their embryological development, pass through stages that correspond to, or are very similar to, the adult stages of lower animals which, in the light of the theory of evolution, would be their ancestors. Thus theoretically we may see, in a way, a moving picture of the history or the evolution of an organ or a system. True, the reel is old, with gaps here and there, with sequence

mixed in places, and even with much unrelated material. Haeckel stated that "Ontogeny is a short recapitulation of phylogeny," which is known as the **theory of recapitulation.** Thus every animal, as it developed from the egg to the adult, was supposed "to climb its own ancestral tree." Psychologists seized upon the theory to explain

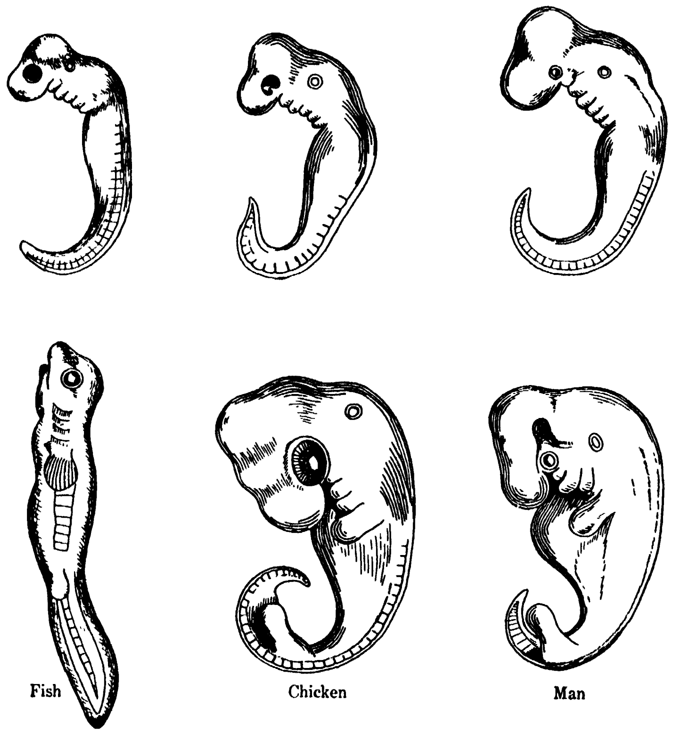


FIG. 337. Gill arches and gill slits in the embryos of fish, chick, and man. (*After Haeckel.*)

types of human behavior, and the sociologist made use of it to explain his problems.

We shall first examine the evidence of recapitulation supporting the theory of evolution and afterward we shall consider some objections to the theory of recapitulation. The early embryologists held the theory of preformation (page 310), but this was succeeded by the theory of epigenesis (page 310), which maintained that the relatively unorganized zygote gives rise to new tissues, new organs, and new systems, forming a new individual. So we have been interested to observe that all the vertebrates with their varied structures and habits have a very similar embryonic history or ontogeny. In tracing

the embryonic history, some compare the zygote to the adult protozoon, and the two-layered gastrula to the coelenterate structure. Restricting our comparisons, we find that at certain stages the embryonic mammal has pharyngeal pouches and gill arches (Fig. 337). Through the gill arches the blood flows, in a fishlike arrangement of blood vessels, from a fishlike heart. We still possess one of these fishy heirlooms, the Eustachian tube, which we believe represents what in our ancestors was a pharyngeal pouch. Embryological evidence seems to indicate that lungs may have had their primitive forerunners in the swim bladder of fishes, as in the lungs of the lungfishes. The very primitive chordates have a rather simple type of kidney called a pronephros which functions throughout life. Fishes and Amphibia in their embryonic stages have a pronephros that is replaced later by a more complex kidney known as the mesonephros, which persists in the adult. As far as the kidneys are concerned, reptiles, birds, and mammals, during the embryonic stages, theoretically recapitulate their early chordate days with a pronephros; their fish and amphibian days are lived through again with a mesonephros, which, in turn, is partially discarded for the metanephros or most complex type of kidney in the adult.

By somewhat similar comparisons of the embryos, we find the Annelida and Mollusca related by their very similar larvas, called **trochophores** (Fig. 164). Often there are countless numbers of trochophores in the ocean, and it is almost impossible for the average person to distinguish between those of the mollusks and those of the worms. If space permitted additional striking similarities among other invertebrate animals could be presented.

What are the objections to the theory of recapitulation? First of all, we must not overlook the fact that many of the structures seen in embryo or larval stages are adaptations to environmental conditions encountered by the young animals. These adaptive structures may have developed irrespective of ancestry. Such larval adaptations or structures Haeckel called **coenogenetic**; the truly ancestral structures he called **palingenetic.** The coenogenetic structures are of recent origin and so can have no ancestral significance, for only the palingenetic characters are ancestral. It was a difficult task to separate the embryonic structures into their proper groups. Many controversies arose, and a marked diversity of opinion was held as to what are coenogenetic and what are palingenetic structures. Consequently there were about as many phylogenetic trees as there were students of embryological evolution. Some of the trees were very poorly rooted. Many biologists became disgusted and were inclined

to scrap the entire theory, but today most of them agree that the fundamental truth of the theory—that many ancestral features are repeated in the development of the individual—is still sound and worthy of consideration.

Also, we are forced to admit that the ancestral history is greatly abbreviated. For example, theoretically, the chick, in the short period of three weeks, lives through an ancestral history covering millions of years. Now the only reasonable view to hold is that much of the history has been omitted and that the remainder is very much abbreviated.

Numerous instances of apparent recapitulation have been observed in the study of the development of plants. The protonema of the moss gametophyte is a threadlike structure resembling an alga, and the early filamentous stage in the development of a fern prothallium likewise recapitulates the structure of certain ancestral green algae. In some conifers the early juvenile leaves of the seedling assume the form of the leaves characteristic of their known ancestors. In the development of the life cycles of group after group, extending from the algae into the gymnosperms, we have already noted the constant recurrence of the ciliated sperms. Thus, in plants as in animals, developmental morphology reveals facts that give sound fundamental evidence supporting the theory of evolution.

Evolution and paleontology. Paleontology is the study of the fossil remains of animals and plants which are found in the rocks of the earth. Fossils for the most part are not organic structures of the original organism but are imprints or mineralized replacements (Fig. 338). The original organic materials have completely disintegrated. Someone has pointed out that this branch of science should present the most convincing testimony for evolution since it deals entirely with ancestral organisms. However, one of the difficulties encountered is that the fleshy structures of many animals and plants do not preserve well. Tissues with a high water content such as we find, for example, in the jellyfishes and many plants, likewise decay without leaving traces. Consequently many fossils are known only from the partial skeletons which have been found, and many types or links needed to complete the chain of the various groups are missing.

Darwin described the situation very well in the following words:

> I look at the geological record as a history of the world imperfectly kept and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume only here and there a short chapter has been preserved; and of each page only here and there a few

lines. Each word of the slowly changing language, more or less different in the successive chapters, may represent the forms of life which are entombed in our successive formations and which falsely appear to us to have been abruptly introduced.

Now it is an obvious commonplace to everyone who sees a brick or stone wall that the layers put down first are at the bottom and that the most recent layers or the ones laid last will be found at the top. So it is with the rock layers or strata. If we examine the

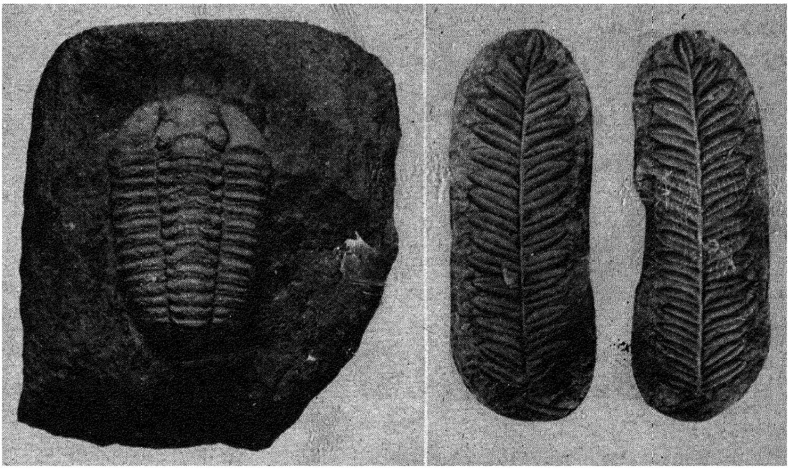


FIG. 338. Fossils. *Right,* a fossil trilobite, an extinct arthropod. *Left,* imprint of a leaf. *Photograph on the right furnished by A. K. Miller; on the left, by H. Lee Dean.*

series of strata often uncovered along roads or exposed by nature, as in the Grand Canyon, we find those formed first, or the oldest from the standpoint of time, at the bottom, and at the top are the youngest or the ones formed last. The geologist has studied exposed rock layers with their contained fossils on various continents and has been able to detect a rather definite chronological succession of these rocks. Beginning at the bottom he has marked off the oldest rocks as those that were formed in the Pre-Cambrian era. On top of the Pre-Cambrian, in order of succession, rest the rocks of the Paleozoic, the Mesozoic, and the Cenozoic eras. The eras show certain peculiar fossil rock formations which furnish a basis for subdividing them further into a chronological succession (Fig. 339).

According to our concept of evolution, viz., that living things are changing and have changed from the simple to the complex, we would

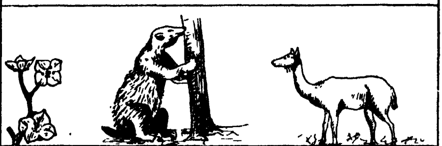
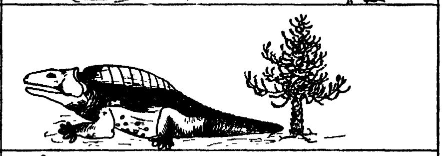
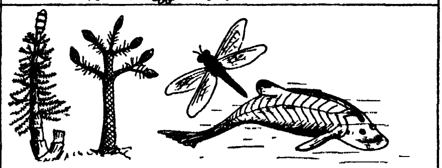
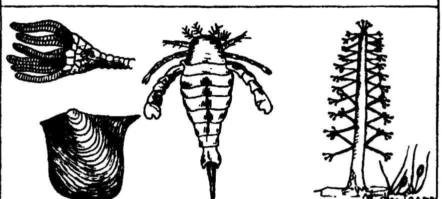
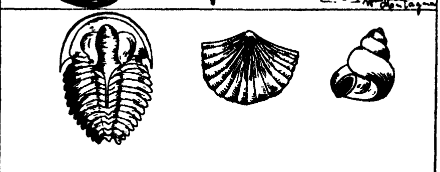
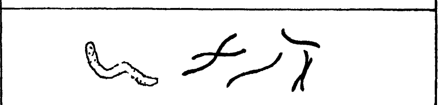
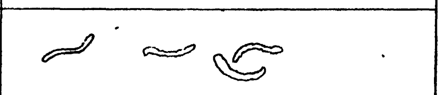
Era	Period	Evolution of Life	
CENOZOIC	Quaternary 1,000,000 yrs.	Development of civilization. Man, domesticated plants and animals.	
CENOZOIC	Tertiary 55,000,000 yrs.	First primates. Modern reptiles and birds.	
MESOZOIC	Cretaceous 120,000,000 yrs. Jurassic 155,000,000 yrs. Triassic 190,000,000 yrs.	First flowering plants. Mammals. Giant amphibians disappear and giant reptiles become dominant. Appearance of highest insects such as ants, bees, moths, and butterflies.	
PALEOZOIC	Permian 215,000,000 yrs.	Trilobites extinct. Tree ferns conspicuous and pteridophytes are the dominant plants. Reptiles are larger and amphibians are increasing in size and number of species.	
PALEOZOIC	Carboniferous 250,000,000 yrs. Devonian 300,000,000 yrs.	First amphibians, lung fishes, bony fishes, and seed plants. Pteridophytes and insects abundant. Club mosses of the size of trees.	
PALEOZOIC	Silurian 350,000,000 yrs. Ordovician 480,000,000 yrs.	Trilobites disappearing. First arachnids (Scorpions) Vertebrates appear. Forms of life increasing rapidly.	
PALEOZOIC	Cambrian 550,000,000 yrs.	Mollusks and brachiopods abundant. Echinoderms and coelenterates are present, also.	
Proterozoic	575,000,000 yrs.	Earliest traces of sponges, worms, and trilobites.	
Archeozoic	600,000,000 yrs.	Beginnings of life. No fossils recorded.	

FIG. 339. Chronological succession of rocks and type fossils.

expect to find the simplest and most primitive animals and plants in the oldest rocks, and the most complex in the most recent formations. This is precisely what the paleontologists find. Unfortunately, the testimony of the rocks yields little information concerning the evolution of thallophytes and bryophytes, for most of these are plants of delicate structure with no resistant parts. Therefore they soon disintegrated, leaving no satisfactory fossil record. From what we know of the role of iron bacteria in causing the deposition of iron in more recent periods, we logically infer that iron bacteria existed in the far remote Pre-Cambrian period when the iron deposits, now being exploited, were accumulated around the western end of Lake Superior. Studies of the morphology and life histories of thallophytes and bryophytes, as we have already observed, reveal a sequence of gradual development from simple to complex forms that strongly suggests the working of evolutionary processes. We have already noted how, in the liverworts, this development brought about a better adaptation to changed environmental conditions and made possible the development of a land flora.

Almost all the fossils of the Paleozoic are marine invertebrates, such as mollusks and echinoderms. There is also a profusion of trilobites, a very primitive group of arthropods (Fig. 338). The rocks near the top of the Paleozoic contain some fossil fishes and a few primitive insects. No mammals or birds are there. As far as the plants of this period are concerned, there were tall, treelike pteridophytes resembling modern horsetails, lycopods, and ferns. There were no traces of our present flowering plants. But in the Mesozoic era (Fig. 339), rocks of which are above those of the Paleozoic and consequently more recent, we find an abundance of conifers and cycads. The fossil record of the pteridophytes and spermatophytes, although fragmentary, is far more complete than that of the two earlier plant phyla. We have noted previously that these plants are characterized by the presence of a vascular system in which there are thick-walled cells forming resistant tissues. Such tissues are more readily preserved, and, accordingly, many more fossils of these forms are available for study. The paleontological record of pteridophytes and gymnosperms is probably more nearly continuous and extends over a longer period of time than that known for any other group, either plant or animal. Studies of this record and of comparative anatomy and life histories have enabled us to picture rather clearly the general trend of evolutionary development in this section of the plant kingdom. There were some primitive birds and mammals, but the vertebrate life of this time was represented by the

highest development of the reptiles. Some twenty orders of Reptilia existed, whose members (Fig. 269) ranged in size from small birds to the huge dinosaurs already mentioned. The bony fishes became more highly developed and more varied. Most of the invertebrates were very similar to modern forms.

Finally, when we come to the Cenozoic rocks, which more nearly approach the present in time, we find fossils which closely resemble modern plants and animals. Flowering plants now suddenly appear, including all forms—trees, shrubs, and herbs—but many of the pteridophyte groups are missing or represented by a few unimportant plants of small size. Among the animals we find the mammals and birds well developed, but only five orders of reptiles are found instead of the twenty that existed in the preceding Mesozoic era. Of the numerous invertebrates of this period we call attention to the higher orders of insects such as the Coleoptera, Hymenoptera, and Lepidoptera. Other arthropods and also mollusks and echinoderms are present in abundance. This rather hasty survey shows that, the farther back we study the history of life, the more differences do we see between those early forms found as fossils in the oldest rocks and those of the present. Moreover, we see no haphazard conglomeration of life forms, but a logical sequence from an evolutionary standpoint. As Scott puts it, "The history of life, both animal and vegetable, is a story of progress and differentiation, of advance continued through millions of years to modern conditions from far-off beginnings, which were of radically different character."

Critics point out that both the fossil and living animal and plant forms which are necessary as connecting links for this gradual transition from one group of organisms to another are sometimes missing. There may suddenly appear new groups of animals or plants which are more highly developed and radically different from the other contemporary forms. A possible explanation for this is that new groups have migrated into new regions, for the geological evidence indicates that at various times in the past the continents were connected by land bridges. Thus the elephants appeared suddenly in Europe at one period and in North America at another. The explanation is that they came from Africa over land bridges which have since vanished (Fig. 340).

We shall describe briefly but two of the many ancestral histories preserved in rocks. To describe all of them would require several volumes. About 1870, Rowe, an English doctor, spent his leisure time collecting from the chalk formations of England fossil specimens of a sea urchin called *Micraster*. He carefully recorded the

level at which he found each specimen in the chalk, and found a variation of the sea urchins increasing progressively from the lowest to the uppermost levels. He found four principal lines of descent, and these in turn showed variations among themselves.

One of the most interesting and complete genealogies is that of the horses of North America (Figs. 341 and 342). The earliest known

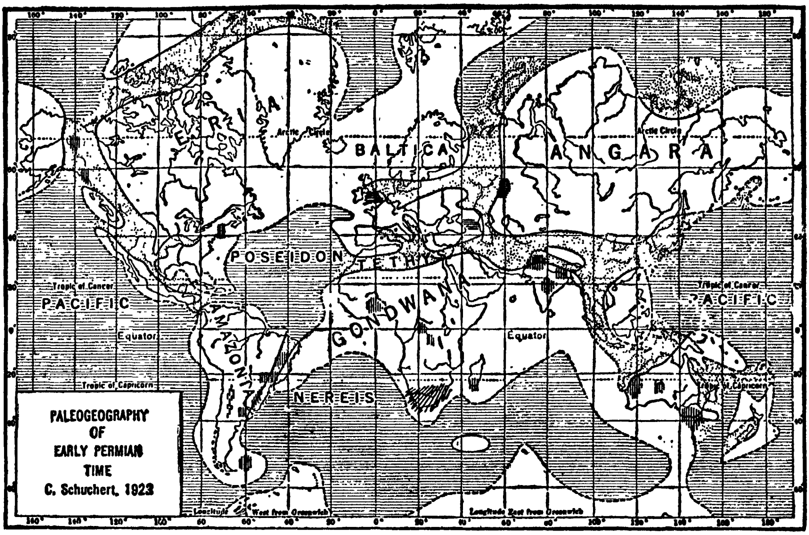


Fig. 340. Ancient land bridges. A study of the map indicates that our present continents were interconnected by areas of lands known as land bridges. Other studies show that North America was connected with Asia in the region of Bering Strait. *From Schuchert and Dunbar, "Textbook of Geology, Part II." By permission of Charles Schuchert and of the publisher, John Wiley & Sons.*

fossil horses were found in Eocene rocks. These little animals were about the size of a well-grown cat and had short necks and legs. They had four functional toes on each front foot and three on each hind foot, together with the vestigial splintlike remains of the first and fifth digits of each foot. As we trace the history of the horse through the rocks to the present, we find that in the Oligocene the horses were about the size of sheep. The ulna and fibula, which are missing in modern horses, were already becoming smaller. The neck was somewhat elongated. The teeth were low crowned. Coming to the lower Pliocene and upper Miocene rocks, we find horses which were about the size of deer, and, although the feet were three toed, the second and fourth toes barely touched the ground and the fifth toe was very rudimentary. The third toe was now coming to bear

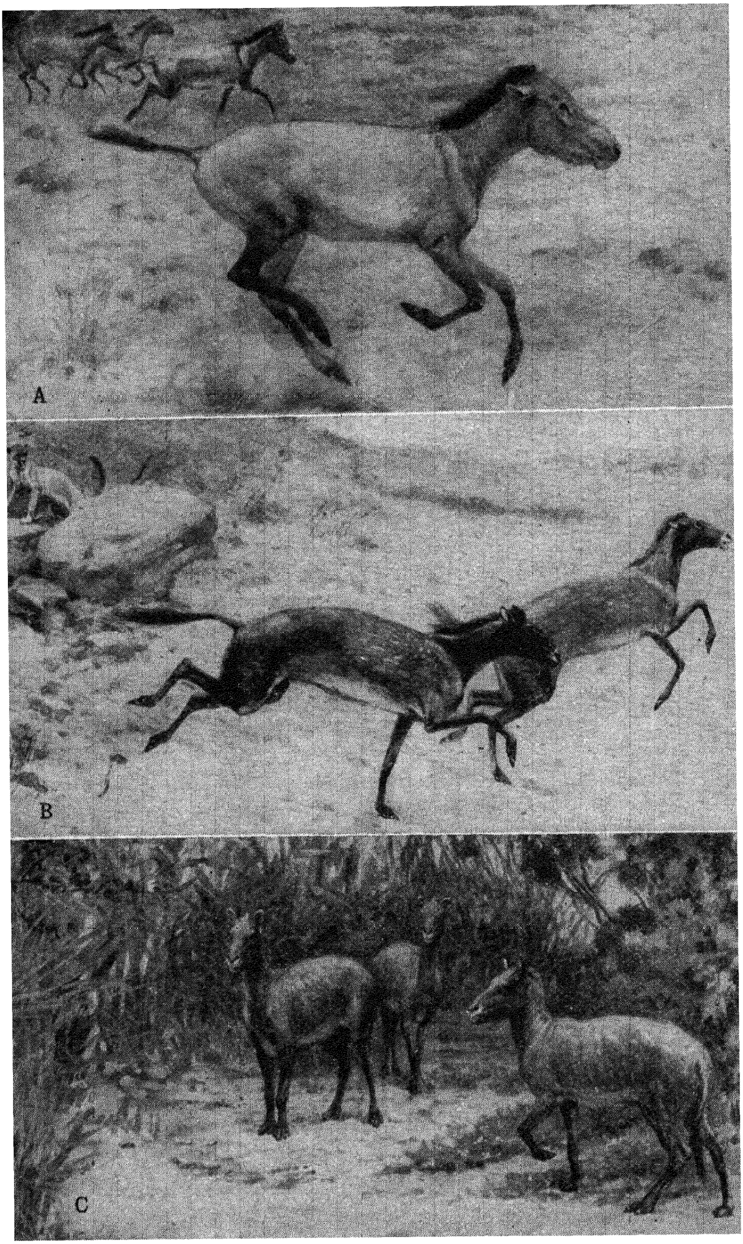


Fig. 341. Restoration of primitive horses. *A*, *Neohipparion*; *B*, *Mesohippus*; *C*, *Eohippus*. *Photographs furnished by the American Museum of Natural History.*

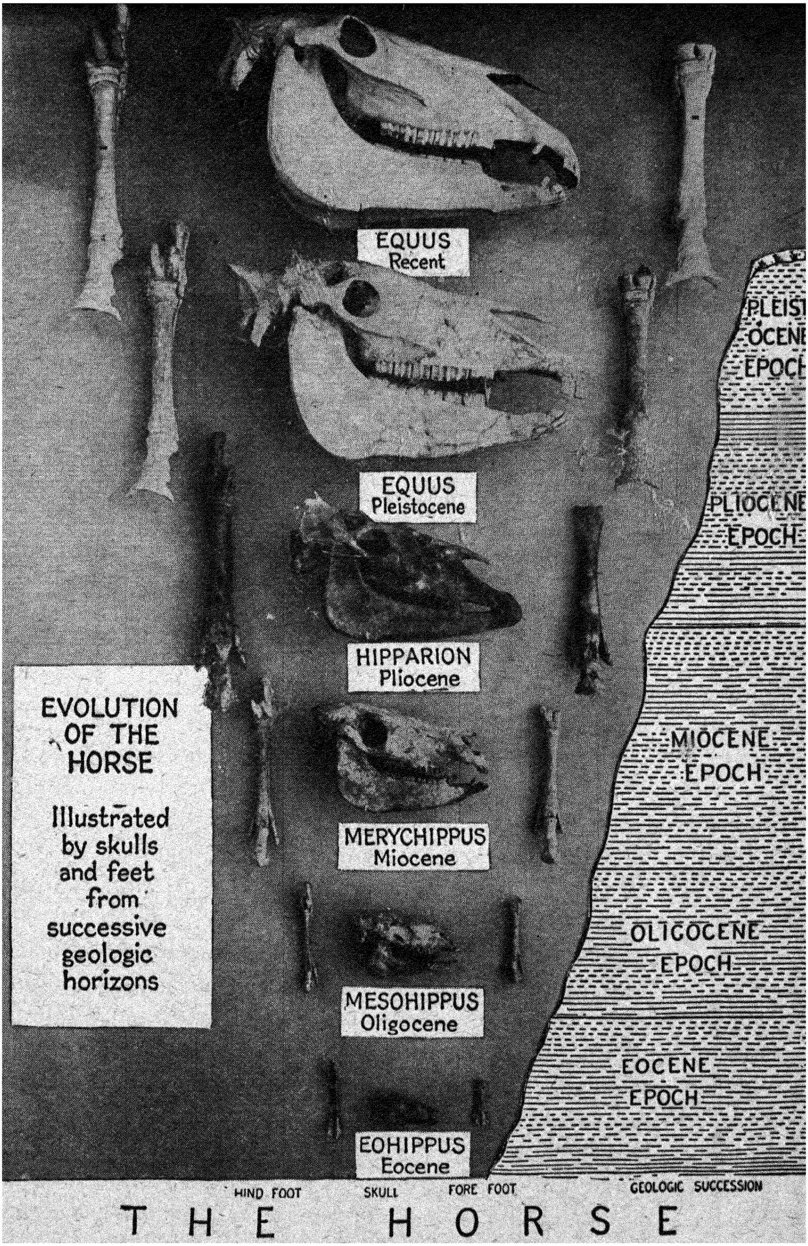


FIG. 342. The evolution of the horse. *Photograph furnished by the American Museum of Natural History, New York.*

the brunt of the burden. The teeth began to have a complicated pattern and were longer. Then, reaching modern horses, we find animals with only the third toe functional, with the ulna fused to the radius, and the fibula fused to the tibia. The teeth are high crowned, persistently growing, and equipped with a complicated grinding surface of dentine and enamel which, wearing away irregularly, leaves a characteristic pattern on the teeth. Both the neck and the face have elongated. Many intermediate stages or connecting links might be mentioned, but this description serves to illustrate the use of paleontology in indicating evolutionary descent.

In addition to the fossil series of the sea urchin and the horse, described above, equally good series of fossils have been found of the elephants and the camels. Many interesting, somewhat isolated specimens have been found which throw some light on the descent of other modern forms. Among them we have already mentioned *Archaeopteryx,* which very definitely furnishes evidence of the linkage of the birds with the Reptilia (page 493).

Evidence from distribution. The distribution and relative abundance of animals and plants throughout the world have always interested men, who, recognizing the value of these creatures and also impelled by their own curiosity, have catalogued and numbered them. We know that certain animals and plants are abundant in some regions and missing in others. Everyone knows that polar bears are found in the arctic regions and that palm trees, lions, and tigers live in the tropics. This distribution might be explained as the result of the influence of climate alone, but on examination, we find various regions with the same climate inhabited by different types of plants and animals. The climate of Australia is very similar to that of Africa, yet the animals and plants of the two regions are very different. Moreover, when various species are introduced into new regions they often flourish in greater abundance than in their original habitat. Here in America we have proof of this statement in the rapid multiplication of the English sparrow and the European starling. The American cactus, introduced accidentally into Australia, has spread over wide areas.

According to the theory of special creation, all this could be explained on the assumption that animals and plants remained where they had been created and placed, for each organism was peculiarly fitted for each environment. But the explanation fails when we find fossil remains of animals whose present forms are found on another continent and when, as has been pointed out, climate does not seem to be the limiting factor. According to the theory of evolution, life,

since its first appearance on the earth, has developed gradually and in orderly sequence. Consequently the distribution of the animals and plants, present and past, will find an explanation in the geologic changes of the former eras, representing the earth's evolution.

Modern geology points out that the face of the earth is constantly changing and has undergone continuous change in the past. In certain regions of the world (Fig. 340) the land is gradually rising, whereas in other places it is sinking. New land emerges at one place, and the sea invades the land at others. Ocean currents shift their courses. Climate changes. At one time, as indicated by fossil plant remains, the arctic region enjoyed a mild and temperate climate. The existence of ancient seas is indicated by the fossil remains of marine animals and plants found in the rocks of the hills and mountains which were formerly at the bottom of the seas. Ancient land connections are shown by soundings taken in various parts of the ocean, also by the present and past distribution of closely related groups of animals and plants. Briefly, these methods indicate rather clearly that North America and Asia were once connected in the area which is now the Bering Sea; that North and South America were once separated by a sea which covered the isthmus of Panama and Central America. Evidence of the former existence of such a sea is shown also by the similarity of fishes in the Atlantic and the Pacific Oceans now separated by the isthmus. Other land connections also have been indicated, such as the connection between North America and Europe by way of Greenland and Scandinavia, and between South America and Africa (Fig. 340).

Now if we find rather similar animals in two different separated regions, it would be logical to infer that the two regions were once connected. Since we find true camels in Asia, and the llamas, guanacos, and other camel-like animals in South America, we must conclude that it was possible for camels to get from one continent to the other. According to geologic evidence, camels first appeared in North America. Later, according to their fossil remains, the true camels appeared in India and the llamas migrated southward to Argentina. Then for some reason—perhaps climatic changes or epidemics—the camels vanished from North America. Knowing of the climatic changes which have occurred in the arctic regions, and that North America and Asia were once connected by a land bridge in the region of the Bering Sea, we can readily understand the mode of distribution.

The converse of the situation just described might be stated as follows: the more distinct and peculiar the flora and fauna of a

given region, the more certain it is that such a region has been isolated for a long time by natural geographic barriers. Such barriers are mountains, rivers, deserts, seas, and climatic differences. Later

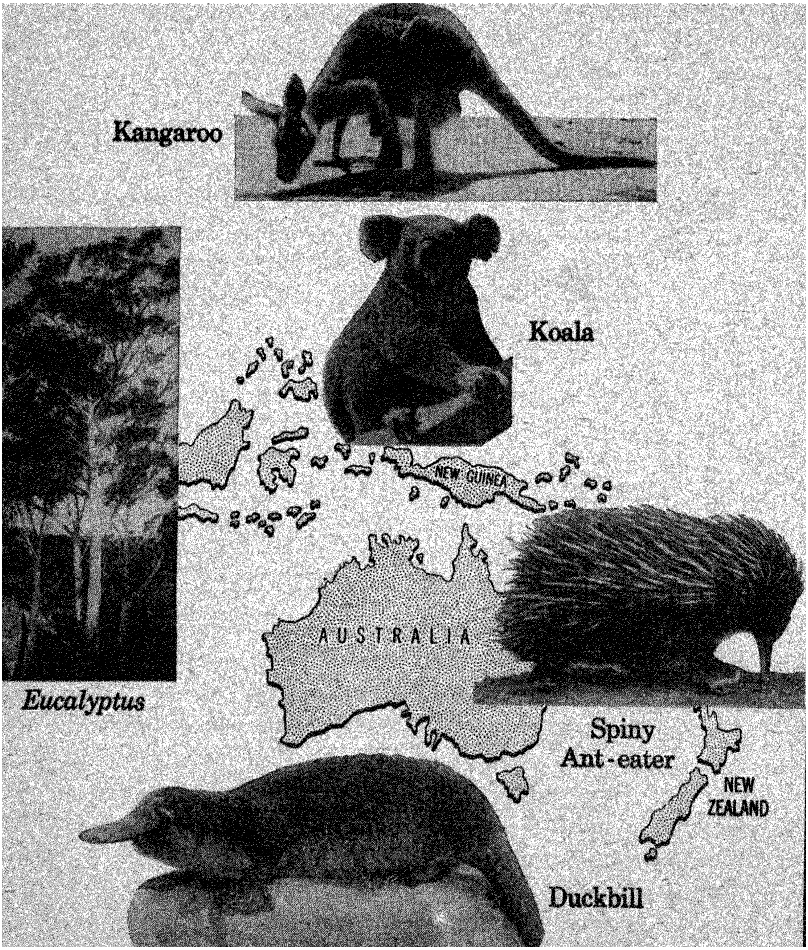


FIG. 343. Map of Australia and neighboring islands; land masses which have been separated from contiguous land for a long period of time, with the result that Australia has a large number of animals and plants peculiar to that region. *Photographs of animals furnished by the New York Zoological Society; photograph of Eucalyptus furnished by the New York Museum of Natural History.*

we shall discuss physiological barriers. In Australia and adjacent islands there are very peculiar animals and plants, unlike any found elsewhere in the world (Fig. 343). Here we find a great develop-

ment of the primitive marsupials—kangaroos, wombats, and even a peculiar marsupial "bear." Geology shows that this region has been isolated from the other great continents for a long time. When we study island life, this theory of isolation is proved in an even more striking manner. Continental islands, such as the British Isles, Sumatra, and Java, are separated from the adjoining continents by a relatively shallow sea and so must have been part of the continents in past ages. The large continental islands usually have a flora and a fauna closely resembling those of the adjacent continent. The oceanic islands, being of volcanic origin and having been built up from the ocean bottom, have never had any connection with the continent. They have a rather limited variety of living forms. According to the evolution theory, oceanic islands should have a limited number of species, since they have to depend for their animal and plant life upon wind, current-borne seeds, animals adrift on floating wood, and seeds carried by birds.

Further, with respect to island life, and more particularly the oceanic island type, the animals and plants which do reach these islands are isolated from their relatives, and so each group may vary to give rise to new varieties and perhaps species. Islands were intensely interesting to Darwin, who studied the Galapagos Islands, and to Wallace, who studied the Malay Islands.

Physiology. We have heard much about blood relationship, but certain experiments and discoveries of the century have added new significance to the term. We have already discussed the preparation and reaction of precipitins. The serum from the injected animal will combine with the protein of the serum of the other animal, forming a precipitate of insoluble protein. In this reaction, the closer the relationship between two different animals, the greater will be the precipitation. A test of the blood of dogs and that of wolves shows almost the same degree of precipitation, thus indicating close relationship. This would indicate not only that animals may resemble each other structurally but that they are similar in their chemical constitution as well. As Newman expresses it, "The blood of an animal is a sort of quintessence of its chemical composition." Bird's blood tested with crocodile's blood gives a precipitate denser than that produced when tested with the blood of any other reptile or mammal. As may be recalled from the evidence of comparative anatomy, paleontology, and embryology, biologists have believed that the birds are related to the reptiles. Precipitin tests show that pigs and cows are related to whales and dolphins—another relation-

ship which had been previously worked out along lines of evidence similar to those just mentioned for birds.

Precipitin tests are used also for the tracing of plant relationships. Many of the problems of the relationships of the ferns and club mosses have been solved by plant precipitins. Here again the evidence from comparative plant anatomy, plant embryology, and paleontology has been substantiated by the serum test. By means of precipitin tests, attempts have been made by certain workers to construct a genealogical tree showing the relationship of plants. Additional physiological evidence of the close relationship and therefore of common ancestry of certain groups of plants is noted in the occurrence throughout of characteristic chemical products, such as the resinous substances in many species of conifers, the mustard oils of the species of the mustard family, the aromatic essential oils produced by plants of the mint family, and the forms of starch grains peculiar to distinctly different groups.

Other physiological evidence of relationship is furnished by the examination of hematin crystals from the hemoglobin of vertebrate blood. Crystals of the blood of different species vary, but those from the blood of animals belonging to the same genus seem to have certain common characteristics. Moreover, hormones from different vertebrate animals seem to have common effects. For example, the hormone from the thyroid glands of cattle may be used to compensate for thyroid deficiency in man. Many digestive enzymes from animals belonging to different groups seem to produce similar effects.

Genetics. In all fields of science, the carefully controlled objective experiment which yields results that can be accurately measured is the most desirable evidence for any hypothesis, theory, or law. This kind of evidence is highly desirable for substantiating the theory of evolution, but the brevity of human life makes a long series of experiments almost impossible, and therefore it is extremely difficult to obtain such evidence. We have said that evolution has been occurring through millions of years, yet the opponents of the evolutionary theory have often made the charge that no one has ever seen evolution actually taking place. Nevertheless, a number of instances are recorded where we apparently do see the appearance of new species.

Most of our domesticated animals and plants are the result of careful breeding of some wild-type ancestor. In the course of breeding, the original animals and plants have been so profoundly changed that we would not hesitate to recognize the derived forms as new

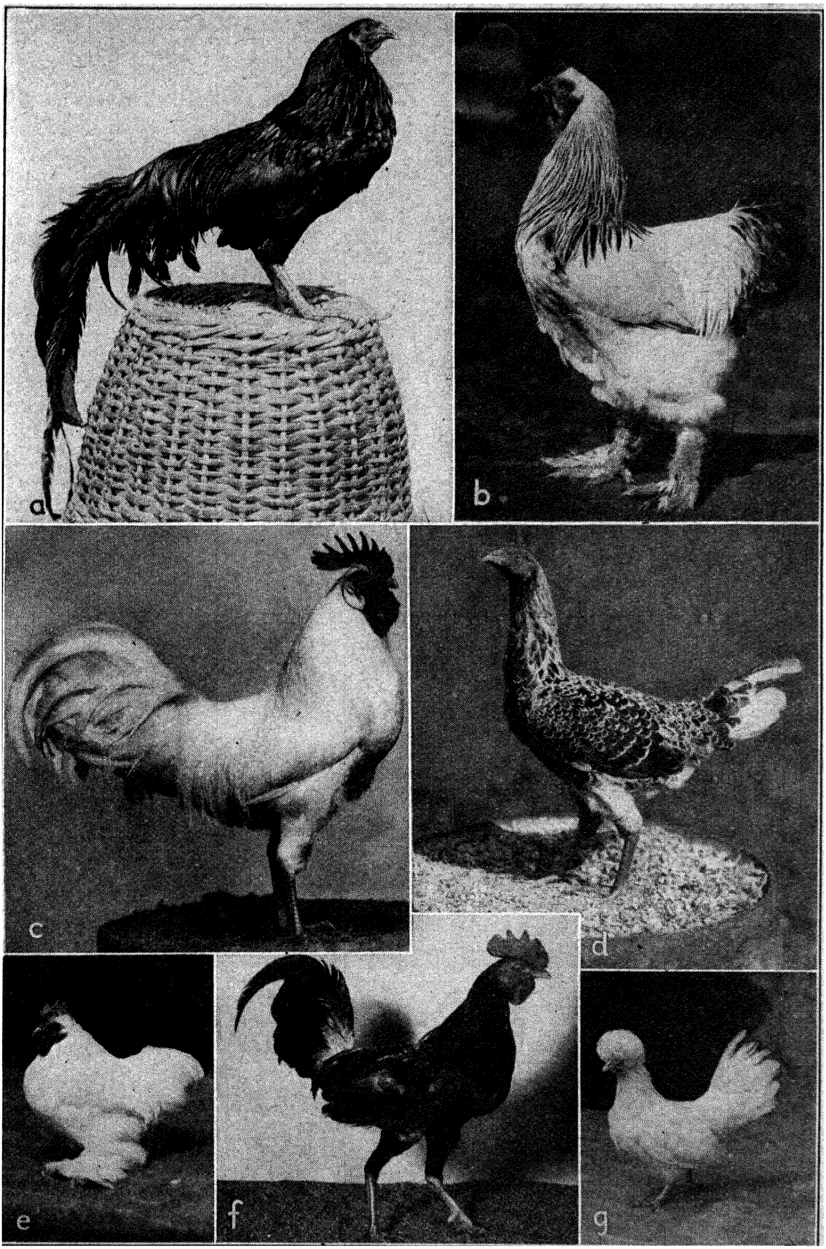


FIG. 344. Various breeds of chickens produced through breeding. *a,* Black Sumatra (male); *b,* Light Brahma (male); *c,* single-combed White Leghorn (male); *d,* White-laced Red Cornish (male); *e,* White Cochin Bantam (male); *f,* jungle fowl (male); *g,* non-bearded White Polish Bantam (male). *Photographs furnished by the U. S. Department of Agriculture.*

species (Fig. 344). Thus the different varieties of pigeons are derived from the breeding of a bluish bird called the rock dove. Dogs are the carefully bred, domesticated descendants of wolves, and the various breeds of chickens have been derived from jungle fowl. In the plant kingdom new varieties of flowers and shrubs are being

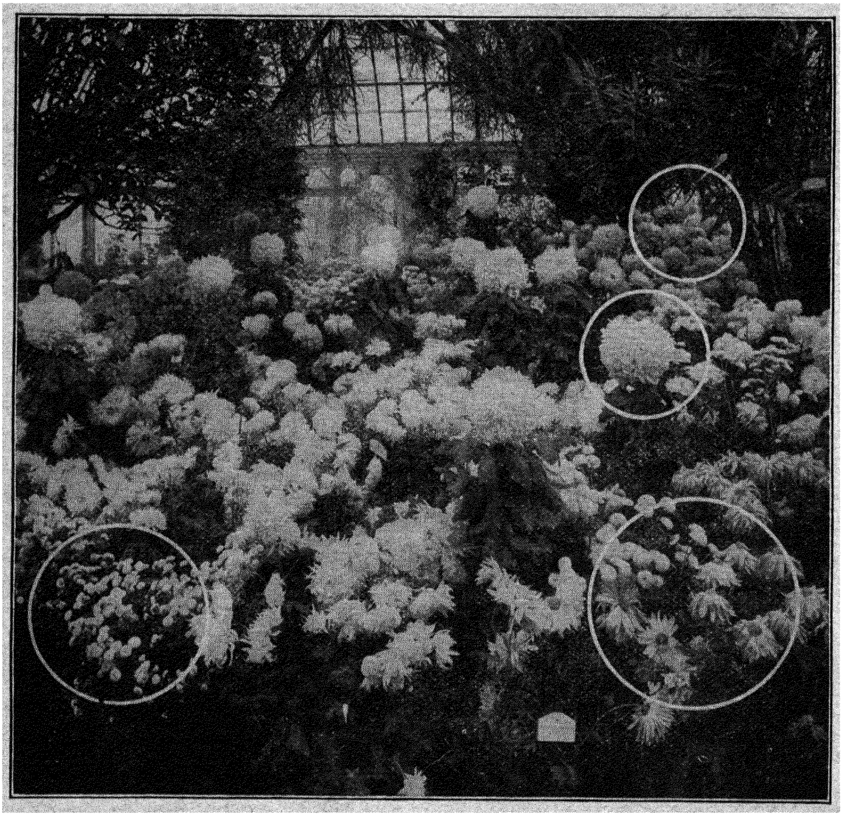


FIG. 345. Varieties of chrysanthemums produced by breeding. *Photograph furnished by the New York Botanical Garden.*

constantly created by the process of breeding. The many beautiful and bizarre forms of *Chrysanthemum* derived by hybridization and selection from the original wild *Chrysanthemum indicum* of China and Japan are so completely different that they may be regarded as new species (Fig. 345).

To trace fully the development of evolution in the animal and plant kingdoms would lead us far afield and away beyond the scope of our present study. However, the brief sketch shows that plants and animals are constantly changing, even though we may not be

able to detect the changes taking place. As a result of the changes, through the medium of the mechanism of inheritance, new forms are evolving. We have seen something of the evidence that compels us to believe that such changes, taking place through the ages, are responsible for the animals and plants of today. Therefore, we are led to conclude that evolution is the process of creation.

THE WORKING OF EVOLUTION

We have previously said that the difference of opinion existing among scientists today is not concerned with the fact of evolution, but rather with the mechanism by which it is accomplished. Even before Darwin's time, Lamarck had suggested an explanation of the changes in organic patterns. Then came Darwin, who, as we have seen, apparently established the fact of evolution and advanced a theory to account for the process. During Darwin's lifetime and up to the present day, men have been striving to find the causative factors which account for evolutionary changes.

Lamarckianism. Lamarck (1744–1829) was a noted French biologist, the youngest of eleven children of a very poor family (Fig. 335). Much against his will, he was educated for the priesthood in a Jesuit College. After the death of his father, he turned to the study of medicine. Later he reorganized the botanical garden and the royal museum in Paris. At the age of fifty he was made professor in invertebrate zoology, a field about which he, like all the others of his day, knew little. Working vigorously and intensively at this new task, he soon became one of the leading authorities in the field. While trying to organize and classify animals he saw how inadequate the theory of fixed permanent species really was. He became convinced that living forms had, in the course of time, been changed into different forms.

Briefly, this was his explanation: The more frequently and continuously an animal used an organ, the more it was strengthened, developed, and enlarged. On the other hand, if it was not used, it gradually, by imperceptible degrees, weakened and finally disappeared. These effects of use and disuse on an organ were inherited. That is, those organs or structures modified by use or disuse in one generation appeared modified in the next. In other words, according to Lamarck, acquired characters *could* be inherited. When, within the organism, a pressing continuous need for some structure arouses and maintains a new activity to supply that need, the new structure or organ can be produced.

Prominent biologists and philosophers like Darwin and Spencer accepted Lamarck's theory, but, as was pointed out in our discussion of the inheritance of acquired characters, Weismann and others were very skeptical about it. The present school of Lamarck's followers, called Neo-Lamarckians, hold that, although the inheritance of the effects of use and disuse have not been proved, it has not been shown that the possibility is not there. Living things do respond to changes in the environment. They are plastic and adaptive. Further, environmental factors, e.g., X-rays, affect the heredity of an animal or individual because they affect the germplasm.

Weismann and De Vries. Weismann's theory of the evolutionary mechanism is really an outgrowth of his theory of heredity based on the continuity of the germplasm. According to this theory, all changes in animals or plants arise from the union of various lines of germplasm which takes place at fertilization. The new genic combinations resulting from these matings bring about changes in the organism. Thus there appear new combinations of characteristics which have always been present in the germplasm. Natural selection then determines which new characteristics resulting from the new combinations will survive.

De Vries (Fig. 335) explained evolution by his mutations theory, which claimed that sudden wide variations or abrupt changes called mutations occur in the germplasm. These changes in the germplasm bring about somatic changes which breed true. Natural selection again determines which of the modified forms will survive and be improved through further mutations in later years. New species thus arise in a single step or by jumps. Doubtless, species do arise through abrupt mutations, but there is some evidence to show that species may be created by the gradual accumulation of slight mutations.

Darwinism. Darwin not only established the theory of evolution on a firm basis but also suggested a theory to explain how evolution takes place. His theory of the working of evolution was based on three premises: **variation, heredity,** and **natural selection** or **survival of the fittest.**

VARIATION. In most respects all organisms may resemble their parents, although they may vary from them in a greater or less degree. No child is the exact image of its parents.

Today, two types of variations are recognized, **somatic** and **germinal.** Somatic variations are acquired and, as has been previously pointed out, may be caused by undernourishment, diet deficiencies, prenatal injuries, hormore unbalance, and the like. A few biologists

think that these changes can be transmitted to the next generation. Gene mutations or other chromosomal changes affect the germplasm. We have already seen how the mechanism of heredity functions to transmit these mutations and changes. Of course, in Darwin's day no distinction was made between these two types of variations. To Darwin the perplexing and important question was how organisms with relatively favorable variations, irrespective of origin, were selected. In his opinion only those that could meet the rigorous demands of life conditions would survive. The unfit would be weeded out by a process of natural selection because only those animals and plants will survive that are so constructed as to be able to adjust themselves to their environment. The next generation would possess the new structural modifications.

Let us see how evolution would operate according to Darwinism. We have already pointed out that many animals lay thousands or even millions of eggs, most of which never produce an adult individual. Many of the eggs never hatch, and many of the young perish before becoming adults. Some fish eggs, for example, are destroyed by burial in the mud, some never develop, and others are eaten by various animals. Moreover, large numbers of the young fry never become adults since they are eaten by such enemies as water birds, water snakes, and other fishes. Some of them are even devoured by their own parents. Some finally reach maturity, but still the struggle continues. Droughts may change streams of pure water into polluted reservoirs lacking normal food supply and low in oxygen. Other factors might be listed that make up this agency of natural selection. It can readily be seen that any fish which can survive under such conditions, in all probability, differs somewhat from the others. This same struggle goes on in the plant kingdom. In crowded areas there is a struggle for sunlight as well as for water and minerals. Frost may claim some members of the plant community before others. Plant parasites and disease may readily invade and kill the plants of some species whereas others are more resistant and escape. It should be emphasized that natural selection does not mean that only those organisms more ideally perfect or most complex structurally survive. It means that only those survive which are better adapted to a certain environment. Thus we find that some animals become adapted to a parasitic life and, in so doing, lose many of their structures. The tapeworm, for example, living in a sea of food, has lost its digestive tract.

In the next place, plants and animals bearing new characters or variations will have a better chance to develop into new species if

they are not swamped by mating with the large number of non-variants. So it has been suggested that the factor of **isolation** must be added to that of natural selection for the effective creation of new species. It has been shown that new types of organisms are developed more rapidly where they are isolated by natural barriers and must interbreed among themselves.

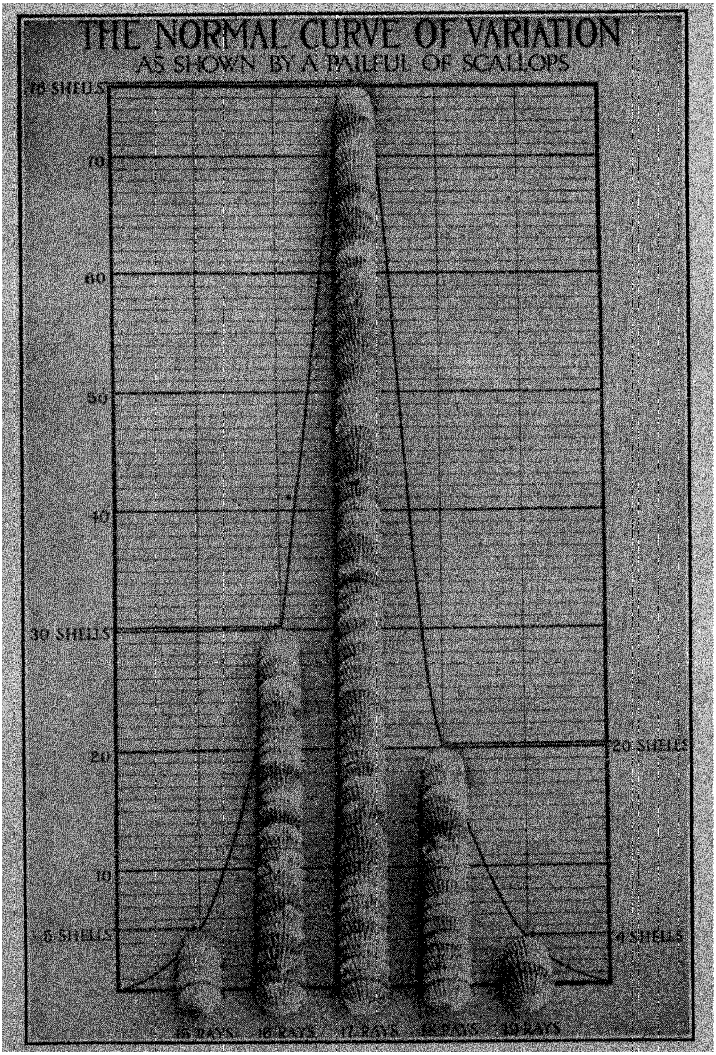


FIG. 346. Variation of animals in nature as shown by the shells of a scallop (*Pecten*, a mollusk). The photograph shows the variations in a number of shells collected at random. *Photograph furnished by the American Museum of Natural History, New York.*

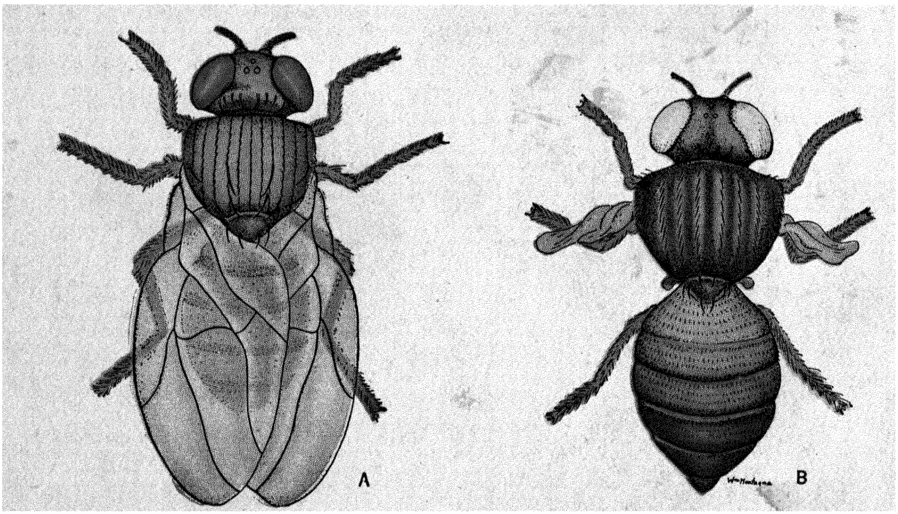


Plate XXVIII. Fruit fly *Drosophila*. *A,* wild-type fly; *B,* a fruit fly showing some mutations from the wild-type fly. About one thousand mutations have been discovered by geneticists since they began the study of the heredity of the wild-type fly pictured in *A*.

There are objections to Darwin's theory of natural selection. Some biologists point out that many of the variations are so slight that they could have no value to any organism in the struggle for existence. Moreover, many apparently useless structures have continued to develop by variation instead of being discarded. Darwin also believed that variations tending toward protective coloration and protective resemblance assisted in preservation, and the recent work of Isely confirms this belief.

Modern conception of the mechanism of evolution. For a number of years, Darwin's suggestion concerning the nature of the mechanism of evolution was severely criticized, and it lost favor. Some of the criticism was directed against his partial acceptance of the theory of the inheritance of acquired characteristics as well as against the way natural selection could operate to preserve small variations. Modern genetics has demonstrated that new species of animals and plants can arise by changes in the chromosomes. Today, as has already been pointed out, we know that loss of parts of a chromosome, interchange of chromosomal parts by inversion, breaking of chromosomes, and duplication of chromosomes may affect the characteristics of offspring. In addition there are changes in the genes themselves which properly are called mutations.

We shall examine an animal and a plant whose evolutionary and hereditary background is well known and changes in which have been carefully observed and recorded. Let us see whether an accumulation of mutations and duplications, or other changes in the chromosomes, can produce a new individual which might be called a new species. Perhaps the most-studied animal has been the fruit fly *Drosophila*. Since the geneticists began the study with the wild-type fly, about one thousand mutations have been discovered. A fruit fly showing only relatively few of these mutations is shown in the colored plate along with the wild-type fly.

A classic example in the plant kingdom is the cross between the radish (*Raphanus*) and the cabbage (*Brassica*). Each gamete of these two plants has nine chromosomes. The zygote, of course, has eighteen. Many of the F_1 hybrids were sterile, but some of them did breed together. When the cells of the individuals of this F_2 generation were examined they were found to contain thirty-six chromosomes, twice the number occurring in the cells of the hybrid parents, and also in the cells of the original radish and cabbage grandparents. Moreover, these F_2 plants bred true. Now what is the appearance of the grandchildren?

Dobzhansky * states that these hybrids "represent a morphological type which is distinct both from the radish and the cabbage (Fig. 347). As chance would have it, the tetraploid ($4n$) has a foliage resembling the radish and a root resembling a cabbage. The fruit is a morphological mixture of both the radish and the cabbage." Dobzhansky declares further that "the uniformity and consistence of the characters, and the obvious differences between the tetraploid (hybrid) and either parental species, leads to the conclusion that we are dealing with a full-fledged new species experimentally created, to which the name *Raphanobrassica* is given to indicate the manner of its origin." Here apparently is an instance where a new species has been created within the knowledge of, and under the direction of, man.

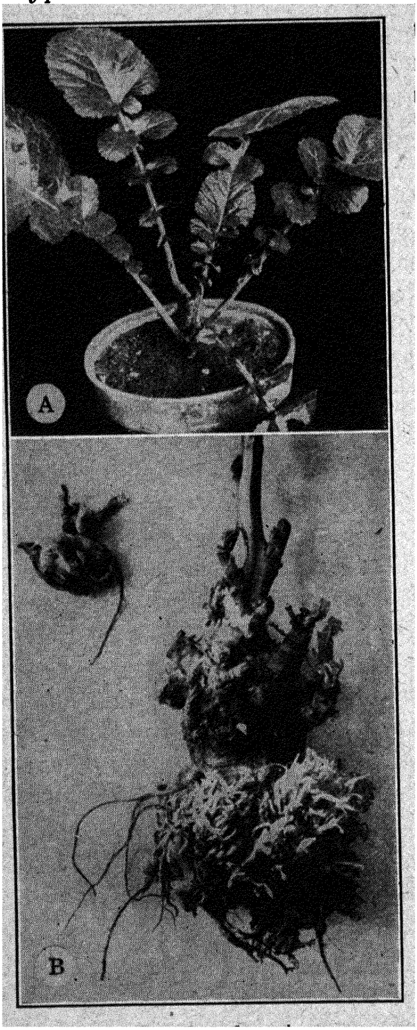


FIG. 347. *Raphanobrassica,* a new genus resulting from the cross between the cabbage and the radish. *A,* stem and leaves resembling the radish; *B,* a portion of the stem and the root resembling that of the cabbage. *Photographs from article by G. D. Karpechenko in Zeitschrift für induktive Abstammungs- und Vererbungslehre, Leipzig, Germany.*

But how can a new species with these new changes persist if the new individuals are surrounded by brothers, sisters, and parents. Under such conditions, one would expect that, by the process of inbreeding, the new characters would soon be possessed by all the members of this species. In other words, the species as a whole would change instead of one certain individual. The result would be a homogeneous population so far as this individual species is concerned. This, as you recall, was one of the

* Dobzhansky, *Genetics and the Origin of the Species,* Columbia University Press, New York, 1937, p. 204.

objections to Darwin's theory of selection. But the present earth population of animals and plants, according to the theory of evolution, owes its large number of different species to new offshoots from pre-existing species.

The factor that prevents free and random mating is **isolation,** of which there are two types, **geographical** and **physiological.** Darwin stressed the influence of geographical barriers such as oceans, mountains, and deserts which made communication among animal and plant groups very difficult if not impossible. Geographical isolation has already been discussed in connection with plant and animal distribution.

Geographical isolation may account for the differences in species living in different regions but cannot account very well for those different species living in the same geographical location. Physiological isolation furnishes the answer here. Some of the physiological isolating mechanisms are as follows: two or more species may reach sexual maturity at different seasons or may have their breeding periods at different times of the year; there may be a lack of sexual attraction between the opposite sexes of two different species on account of differences in scents, courtship behavior, and the like; differences in the structure of the sexual apparatus may make coition impossible; pollen tubes may fail to reach the ovule; hybrids may be sterile. The agencies of both geographical isolation and physiological isolation may tend to preserve the new characters appearing in animals and plants which differentiate them into new species.

From what has been said it is clear that the race that will evolve most rapidly is the one with the shortest reproductive span. For example, a new generation of *Drosophila* can appear in twelve to fourteen days, whereas an elephant has a gestation period of about twenty months and at one time can produce only one offspring which reaches sexual maturity only after ten years.

A second factor that influences evolution is the mutation rate of the species. Thus one species of a snapdragon plant has a rate as high as 10 per cent of the offspring of each generation, whereas another species has not shown any mutation in more than twenty years. Races with slow mutation rates may exist for ages without change.

When we compare the studies made by Darwin, Weismann, and De Vries we find that all have made some contribution to the modern conception of how evolution works. Weismann showed the supreme importance of the germplasm as compared to the somatoplasm. De Vries clarified the variation concept by developing the mutation theory, and Darwin, by his idea of natural selection or survival of

the fittest, showed how it is possible for only certain types of mutations to persist and lay the foundation upon which other changes may take place. His principle of natural selection is now more firmly established than ever as one of the factors of evolution.

Orthogenesis. Orthogenesis (*orthos*—straight; *genos*) or determinate evolution maintains that variations in animals and plants do not take place by chance or at random but that they follow in definite lines or directions either under control of an "internal perfecting principle," according to Nägeli, or of "the laws of growth." Orthogenesis goes on independently of natural selection and may continue to add "improvements" to the race even though the improvements have no value. Such determinate evolution might lead to overspecialization and result eventually in the death of the race.

EVOLUTION IN MAN

Many people have been willing to admit that evolution may occur in plants and animals, but they refuse to concede that it occurs in man. Indeed, some have been unwilling to consider man an animal. In the light of what has already been said it would be absurd to question man's animal characteristics. As far as man's evolution is concerned, there is abundant evidence from embryology, comparative anatomy, and other fields to illustrate his emergence from other forms.

No evolutionist maintains that man sprang from any of our present-day apes and monkeys. On the contrary, it is thought that millions of years ago there was an apelike group of animals which gave rise to two branches. The first branch included the arboreal apes, and the second was a terrestrial group, the man animals. By the process of evolution man emerged from this apelike stock as a "new creation." The anthropologist (*anthropos*—man; *logos*) tells us that it seems evident that the human family had its origin in Asia or Africa and spread by migration in successive waves over the now vanished land bridges to the various parts of the world.

However, it is hard to trace early human history, for there have been comparatively few "finds." Early man, low in intelligence as he must have been, was able to avoid the pitfalls of the water hole, quicksands, and tar pools which claimed so many of the lower animals. Asia, often called the "cradle of the race," and Africa have been little explored. As we consider this very brief outline of the

story of early man, we must remember that the conclusions are based on observations not of complete specimens, but rather of fragmentary, fossil, skeletal remains. Knowledge of present-day savages, comparison of the skeletons of man with those of the present-day great apes, as well as a study of the life of these living animals and the biology of modern man—all afford evidence of the origin and evolution of modern man. When compared with the age of the earth and the time span of animal and plant life since its first appearance, man has appeared so recently that he has fittingly been called a "zoological upstart."

Most of the remains of earliest man have been found in the rock formations of the Pleistocene era, which began over a million years ago. The age, as well as the food habits and social life of early man, is inferred from the fossil remains of other animals and crude utensils which are often uncovered in the same location with the remains of man himself. For example, the bones of a certain type of fossil man in Europe were associated with those of the mammoth, the rhinoceros, the saber-toothed tiger, and other animals. These animals are now extinct, but their abundant fossil remains from various locations in the world have enabled the scientist to locate definitely in the geological time table the strata in which they occur. Stone weapons sometimes made of chipped flint, polished stone axes, charred bones and wood—all suggest something of the social life of these early men (Fig. 348).

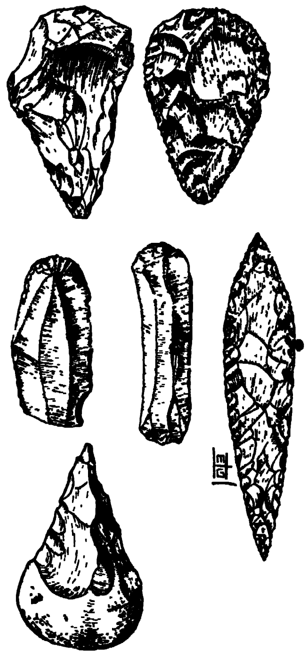


FIG. 348. Early stone flints used by primitive man.

A study of the weapons and utensils of man, that is, first culture, indicates that we are now living in the Iron Age, which began about 3,400 years ago. Previous to the Iron Age was the Bronze Age, which began approximately 4,900 years ago. Copper was used about 1,000 years before the alloy, bronze, came into use. From 6,000 years ago, back into the dim recesses of man's history, stretches the Stone Age. In the recent Stone Age, the "cultural fossil" (utensils, weapons, and the like) seems to indicate that there was some domestication of animals and cultivation of plants. Some pottery was made, and the construction of crude huts for living quarters began.

The following from Hooton* will serve to illustrate how short has been man's stay and development on the earth compared to the total geologic age of the earth.

"Now if we revert to Dr. Chester Reed's radio-active chart of geologic time, we find that he assigns one million years to the Pleistocene period and six million years to the Pliocene. The anthropologist is wholly incompetent to judge of the validity of such scales, but the present writer prefers to be a radio-activarian rather than a sedimentalist. Then, if we plagiarize Dr. Reed's radioactive clock, we find that the twelve-hour dial of man's culture represents no less than four million years. Each second represents 92.59 years. Accordingly, if man's culture was born at mid-Pliocene noon, he began to make Chellean fist axes at 9 P.M.; at 11.54 and 36 seconds he began to draw pictures of animals and to sculp his lady friends; and at 11.58 and 12 seconds he was beginning to try to tame animals and plants, to build huts, to live in communities, and to polish stone tools; at a little less than 37 seconds before 12 o'clock midnight he discovered the use of iron. Of course this cultural-archaeological clock is hardly accurate enough to justify the splitting of seconds."

We shall now examine some of the most important types of early man representing "missing links" which chain man in some measure to his ancestry.

Java man. In 1891, Dr. Dubois, a Dutch army surgeon, found a deposit of fossil bones in Java. Among these bones of various animals, he found first a human tooth and, about a yard away, the top of a skull, and finally, the left femur and two more teeth. Dubois had set out for the East Indies to look for a missing link, and he found it. The teeth are essentially human, but in some respects they resemble those of the higher apes. The femur is definitely human and by its structure and shape indicates that the owner walked erect. The skull was somewhat apelike, with heavy brow ridges. In addition to the prominent bony ridges over the eyes, the Java man probably had a heavy, powerful jaw and a flat nose (Fig. 349). Dubois called this animal *Pithecanthropus erectus,* or the erect ape man. It was estimated that the brain capacity of this early fossil man was about 940 cubic centimeters. This is considerably less than that of the modern European, whose brain capacity is approximately 1,450 cubic centimeters.

The Piltdown man. In 1912, an English lawyer who was interested in geology as a hobby accidentally discovered fragments of a cranium, a portion of a lower jaw with teeth in place, and some portions of the nasal bones. The fossilized fragment of the skull was part of a brown "cokernut" (cocoanut) which English workmen had uncovered. After these fragments were found, a diligent search

* Hooton, *Apes, Men, and Morons,* G. P. Putnam's Sons, New York, 1937, p. 55.

Fig. 349. Types of early man. *A*, Java man (*Pithecanthropus erectus*); *B*, Neanderthal man (*Homo neanderthalensis*); *C*, Piltdown man (*Eoanthropus dawsoni*); *D*, Peking man (*Sinanthropus pekinensis*); *E*, Cro-magnon man (*Homo sapiens*). *Photographs A, B, C, and E furnished by J. H. McGregor; D furnished by Science Service.*

brought to light more fragments of the skull, but apparently other fragments of the "cokernut" were removed with the gravel which went into the road building. A reconstruction based on the remains shows a man with heavy jaws and receding chin, but with higher forehead and greater cranial capacity than the Java man (Fig. 349). This man was named *Eoanthropus*, or the "dawn man."

Peking man. Another discovery of the remains of ancient man was made near Peking, China. From the standpoint of number of specimens uncovered, this is perhaps the most complete "find" of fossil material representing men of the earliest period. Here has been uncovered a wealth of material consolidated in the debris of an old cave whose roof had collapsed. The skulls are small, narrow, and apelike, with great, bony ridges above the eyes (Fig. 349). The forehead is low, and the nose is broad. The basal parts of the skulls are missing, suggesting that they had been removed for the extraction of the brains by cannibalistic enemies. Brain casts of the inside of the skulls indicate that the brain resembled somewhat that of the chimpanzee. In addition to the skeletal remains, stone implements and ashes from ancient fires were found. The Peking man is known as *Sinanthropus.*

The three types of early man just described apparently lived at the same period in the earth's history, the Pleistocene era. The Peking man may be but slightly more advanced than the Java man, and the Piltdown man may have been further advanced than either of the other two. Both the Java man and the Peking man seem to be members of a line which led to a later group of primitive men known as the Neanderthal man.

The Neanderthal man. Unlike the fossil remains just described, practically the complete skeleton of the Neanderthal man is known. Many fossil remains of this race have been found in various parts of Europe and Asia, but the earliest specimen was found in the Neanderthal gorge in Germany. Apparently, these men had large faces, enormous ridges above their eyes, and low retreating foreheads. The teeth were large, and the jaw was minus a chin projection. These men were a little over five feet in height, with a forward-thrust head and curving thigh bones (Fig. 349). Their cranial capacity was fairly large, but they were low browed and probably not intelligent. From other remains associated with the Neanderthalers, we conclude that they were skillful workers in flints, and that they lived in caves where they gorged on choice bits of food from the woolly mammoths, the woolly rhinoceroses, and other animals. They prob-

ably wore clothing of animal pelts, and there are indications that they used torches dipped in animal fat.

Concerning the relationship between the Neanderthal man and modern man, there are two schools of thought. One group would derive modern man from the Neanderthal group, although at present no transitional types have been found. Another school holds that modern man split off from the ancestral line of the Neanderthal man and evolved separately somewhere in Africa or Asia. In other words, we are not direct descendants of this group, but may be, as Romer points out, "Neanderthal man's progressive nephew." Apparently some evidence for this last statement is afforded by discoveries in Palestine, near Mt. Carmel and the Sea of Galilee. Here fossil men have been uncovered which resemble modern man more than the European Neanderthal. Perhaps the Neanderthal men developed in Asia and Africa and later invaded Europe, as did the other animal forms found in Europe.

There is no doubt that another race of men invaded Europe after the Neanderthals. Their remains are found in caves and layers of debris above those containing the remains of the Neanderthal occupation. It may be that this later race, the Cro-Magnon, drove out or annihilated the Neanderthal race in Europe. Apparently the Cro-Magnon race moved in from the east, that is, from Asia or Africa, and it is logically conceivable that they may have developed there to their high racial state.

Cro-Magnon man. Judging from the remains found in a grotto near Cro-Magnon in France, this was a magnificent race whose men were more than six feet tall. As indicated by the shape and size of the head they must have been quite intelligent. They had a firm, well-developed chin, shortened jaws, prominent nose, and the high forehead of modern man (Fig. 349). They evidently knew how to use a bow and arrow. On the walls of their cave dwellings there are pictures and sculptured figures of various wild animals indicating that they had some interest in art and sculpture. The collection of weapons and utensils found interred with their remains may indicate a religion and a belief in immortality.

From what has just been said, one can gather that the types of primitive man just described as well as other primitive types may be regarded as intermediate steps in the development of modern man or as offshoots from the main family tree. Certainly it must be evident that these different fossils of early man do not represent one continuous line of descent. Considerations of fossil findings are in-

Fig. 350. Reconstruction of Neanderthal family group at Gibraltar. *Photograph furnished by the Field Museum of Natural History, Chicago.*

teresting in that they may indicate *in a general way* some of the stages in man's development.

Races of man. In the scheme of classification used for the plant and animal kingdoms, we have seen that those forms which resemble one another most closely are grouped into species. In many instances, different species are not interfertile and so do not interbreed. Under the category of species there may be subgroups known as subspecies, and under subspecies come other groups known as races. Keeping in mind that animals of the same species were supposed to resemble each other very closely, and that subspecies were supposed to resemble each other even more closely, one can readily understand that animals or plants belonging to various races differ but little from one another. Thus it is clearly realized how difficult it is to separate members of one race from those of another. This is particularly true of man. Attempts have been made to separate races of man on the basis of common language, similarity of social and cultural traits, and, finally, differences in physical traits. It is apparent at once that language and social traits may be readily changed when one group of people adopts the language and traits or culture habits of another group. Such adoptions may be brought about by choice or by force. A good example of the adoption of a culture habit of other races is furnished by the American Indian, who replaced bow and arrow with powder and ball, from both necessity and choice, and maybe by imitation.

Of all the distinguishing features peculiar to race, the physical traits are the most dependable, but here again difficulties arise because races are interfertile and can interbreed. Thus it is difficult to find a pure race. In fact, it is doubtful that one exists. Some of the physical characteristics most used in the differentiation of race are skin color, type of hair, shape of head, stature, and often eye shape and color. Today, students of race recognize five main races.

THE NEGROID RACE includes members who have dark complexions, flat noses, woolly hair, and long heads. They are found mostly in Africa south of the Sahara and in certain oceanic islands. The pygmies from various regions of the world belong to this race.

THE AUSTRALOIDS are long headed, flat nosed, and dark complexioned. However, they differ from the Negroid in that the black hair is wavy rather than kinky, and the body is more hairy. Apparently they make up a group intermediate between the Negroid race and the peoples of Europe. Australoids are found in Australia, in southern India, and in the Malay region. The race is almost extinct.

THE MEDITERRANEANS are long-headed, narrow-nosed people with light and brown complexions. They have wavy hair. This race includes those peoples bordering the Mediterranean Sea, including Egypt, southern Italy, some sections of western France, the British Isles, and the majority of the people of India. The members of the "Nordic race" comprize certain groups from eastern England, Scandinavia, and northern Germany. Interestingly enough, you will note that not all Germans are Nordic in characteristics.

THE ALPINES are the broad-headed peoples of Europe and western Asia. They have light to brown complexions and wavy hair. Asia seems to have been the seat of origin of this group, which spread into eastern and central Europe. They live in a broad belt which includes most of the east Baltic, eastern Germany, Austria, northern Italy, Switzerland, and part of France. The Slavic peoples also belong to this group.

THE MONGOLOIDS are another race of broad-headed people, with straight hair and yellow or red skin. Another feature often present is the "slant eye," a characteristic brought about by the presence of a fold stretching from the upper lid which overlaps the lower at the inner corner of the eye. This race includes the Chinese, Japanese, Malays, and other groups in Asia, as well as the Eskimo and the Indian peoples of the two Americas. Geologically speaking, it is probable that the Americas were peopled very recently. It is quite possible that the original Asiatic stocks crossed into America by the long-vanished land bridge between Alaska and Asia, or ventured to cross the narrow Bering Strait by raft or boat. From this they spread southward over the Americas in successive waves.

SUMMARY

We have pointed out that evolution means descent with modifications, and that new species of animals and plants appear which differ from those of the past. This view of organic creation is different from the doctrine of special creation, which postulates that all living things were created at a certain time by special fiat. According to evolution, we live in a dynamic, changing world instead of the static, non-changing world of special creation.

The fields of comparative anatomy, paleontology, embryology, blood tests, classification, and genetics lend support to the theory. Scientists are agreed as to the fact of evolution, but there are disagreements as to the process. Apparently modern man has reached his present physical form as a result of evolution.

INDEX AND GLOSSARY

(Illustrations occur on pages referred to in bold-face type. Colored illustrations which have no folios are referred to by the page they face.)